INVESTMENT BEHAVIOR OF REGULATED ELECTRIC UTILITIES IN THE UNITED STATES, 1964-1977

BY

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This dissertation is dedicated

to my mother whose love and support

were a constant source of inspiration

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Finally, the author claims responsibility for all mistakes.

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Previous studies of investment behavior of regulated electric utilities have overlooked the fact that firms in this sector are subject to rate-of-return regulation. Such regulation constrains them to a maximum rate-of-return on their invested capital. In this study, the regulatory constraint is introduced into the firm's maximization problem. It is shown that rate-of-return regulation will affect the user cost of capital and thus influence capital expenditures.

The formulae employed in calculating the user cost of capital also account for the effects of changes in federal tax policy. Since investment behavior in this period is best explained when the user cost of capital is reduced slightly, there is some indication that the Averch-Johnson effect may, in fact, occur. It is recognized that rapidly escalating fuel prices and increasing expenditures on pollution control facilities may be the source of any overcapitalization in the industry during

this period. However, the effects of increased power pooling may serve to mitigate these results. To the extent that overcapitalization cannot be attributed to factors other than rate-of-return regulation, the validity of the Averch-Johnson hypothesis may be tested by the approach presented in this study. A methodology which incorporates the investment behavior of regulated power and light companies would seem to offer a most appropriate test of a hypothesis which predicts overcapitalization in an industry facing rate-of-return regulation.

CHAPTER I

INTRODUCTION

Privately owned electric utilities in the United States invested \$19.76 billion in new plant and equipment in 1977 [1]. This represents 90.9 percent of all plant and equipment expenditures in the total electric industry. It is approximately 75.6 percent of all such expenditures by public utilities (including telephone and gas) and 26.0 percent of new plant and equipment expenditures by the nonmanufacturing sector of the U.S. economy. Since new plant and equipment expenditures by all industries was \$137.02 billion, investor-owned electric utilities accounted for 14.4 percent of all expenditures on new plant and equipment in the U.S. [2]. Although this figure is slightly lower than in the past, it still represents a significant proportion of total investment expenditures. Since more than one-seventh of all plant and equipment expenditures in the U.S. are attributable to this segment of the electric utility industry, the companies comprising this sector make a substantial contribution to investment fluctuations. However, the regulatory environment in which these utilities operate serves to distinguish them from most other industries. Firms must meet consumer demand at prices set by various regulating agencies. Furthermore, rate-of-return regulation may have an effect on the user cost of capital faced by these firms. It is the purpose of this paper to examine this possibility and analyze investment behavior in this sector of the economy.

The amount and timing of fixed capital investment in the electric utility industry has been shown to depend on the cost of fixed capital which in turn reflects economic forces outside the regulatory environment [3]. If rate-of-return regulation affects the cost of fixed capital, then such regulation indirectly affects the amount and timing of investment expenditures in this sector of the economy.

This study is confined to privately owned electric utilities and attempts to modify the econometric model of investment behavior in U.S. regulated industries developed by Jorgenson and Handel [1971] such that it more closely reflects the theoretical construct of a firm facing a rate-of-return regulatory constraint.

Notes

[1] These figures are as per the Edison Electric Institute [1978].

[2] These figures are as per the U. S. Department of Commerce [1977].

[3] Rennie [1977] has demonstrated that federal tax policy does affect electric utility investment.

CHAPTER II

THE INDUSTRY

The electric power industry may be divided into two segments: (1) investor-owned firms which furnish about 79.0 percent of the total public energy supply and (2) other electric power facilities owned mainly by federal, state, and local governments which account for the remaining 21.0 percent [1]. Since privately held utilities supply an overwhelming proportion of our energy needs, it seems rational to focus on fluctuations in the capital expenditures of these firms when examining determinants of investment behavior in the industry. Further, investor-owned electric utilities are faced with a regulatory environment which seeks to constrain their overall return on invested capital. Municipal, federal, and REA cooperatives are subject to no comparable restraint. Thus, the two segments of the electric power industry must be studied separately.

Since 1958, privately owned electric utilities have added subtantially to their total generating capacity (see Table 1), the compound growth rate for the succeeding twenty years being approximatly 7.6 percent. However, as Table 1 demonstrates, average annual growth rates have fluctuated widely (between 4.0 percent and 10.8 percent during the period).

Although generating capacity, measured in terms of kilowatts (kW) installed, does not include all the facilities of the industry, it composes a considerable proportion of the facilities to which all other parts of the capital stock are largely geared (see Table 1). It also constitutes the largest part of any electric utility's investment. Thus, wide fluctuations in the growth rate of installed generating capacity

TABLE 1

INSTALLED GENERATING CAPACITY OF PRIVATELY OWNED ELECTRIC UTILITIES

Year	Total Installed Capacity MW (000)	Average Annual Percent Change (%)	Production, kWh per kW of Capacity (kWh)	Production As Percent of Plant In Service (%)
1958	108	10.9	4,537	41.5
1959	119	10.2	4,571	42.4
1960	128	7.6	4,523	40.5
1961	137	7.0	4,416	40.7
1962	145	5.8	4,490	42.5
1963	158	9.0	4,437	42.0
1964	168	6.3	4,500	41.7
1965	178	6.0	4,545	41.1
1966	186	4.5	4,737	40.4
1967	204	9.7	4,549	40.2
1968	221	8.3	4,611	40.0
1969	240	8.9	4,592	40.1
1970	263	9.6	4,498	40.2
1971	287	9.1	4,355	40.3
1972	314	9.4	4,328	41.3
1973	348	10.8	4,172	42.4
1974	377	8.3	3,825	44.3
1975	399	5.8	3,727	45.7
1976	415	4.0	3,812	46.5
1977	436	5.1	3,862	Not Available

Source: U.S. Bureau of the Census [1959-1978] and U.S. Federal Power Commission [1954-1977].

Note: Average Annual Percent Change reflects the change from the prior year; for 1958, change is from 1957.

lead one to surmise that the level of investment also experienced substantial fluctuations from year to year (see Table 4).

These firms supply most of our energy requirements. During periods of above average annual growth rates in capacity, their rate of utilization exhibited a strong downward trend (see Table 1) [2]. Given these facts and observing the great variations in the annual growth rate of installed capacity, it is of considerable economic interest to analyze the determinants of their investment behavior over this period.

Part of the explanation for the divergence between increments in energy requirements (or demand) and the level of investment in the industry hinges on the environment in which these firms operate and the basic problems they face which differentiate the regulated electric utility sector from the rest of the economy.

Electric utilities experience relatively long lags between the planning and completion stages of new generating units. These lags have become more pronounced with the advent of nuclear facilities and additional environmental regulations. Consequently, decisions to expand and the actual culmination of the expansion have become increasingly removed in time.

Due to these longer and longer lags, firms have been forced to project expected demand farther and farther into the future. Since they are granted a monopoly status in the area in which they are franchised, they are under legal obligation to meet demand within their service area. Their prediction techniques have historically lacked in sophistication, resulting in rather poor estimates of demand for periods such as 1973-1974 where deviations from the normal historical trend occured and could

not be predicted within their forecasting framework. Underestimating the effect of inflation on prices and income, the effect of saturation on future energy requirements and the possible effect of diminishing returns to scale on their costs, electric utilities are likely to have overestimated their required capacity.

Exploring the investment decisions of these firms is especially relevant in light of the heavy capital requirements of electricity production. The process is characteristically capital intensive relative to the labor employed. Technologically, the productive process allows little scope for substitution between capital and labor and storage of the product is presently infeasible, except for pumped storage.

Electric utilities have historically experienced increasing returns to scale. Their monopoly status is granted partly on this premise. It is not clear, however, that all firms are still able to reap such economies of scale. An analysis of the investment behavior of regulated electric utilities should at least consider the possibility that firms operate in different regions of the production function. Estimates of scale coefficients would help determine whether or not increasing returns to scale still exist in the industry.

There exists a low rate of capital turnover in the industry. This is largely due to substantial capital investments of great longevity. Today firms generally find it impossible to finance extensive construction programs by means of retained earnings and/or depreciation accruals alone. Their major source of financing is likely to be the capital market, giving interest rates an opportunity to play a major role in investment decisions.

Finally, Averch and Johnson [1962] point out that investor-owned electric utilities are subject to rate-of-return regulation which constrains them to a maximum rate of return on their invested capital. Since this constraint must enter the profit-maximization problem of a regulated electric utility it may affect the firm's investment decisions to the extent that the constraint is binding.

Chapter III examines prior studies of investment behavior. There are relatively few that have dealt with the regulated electric utility industry per se. Of those that have, each seems to address some of the aspects relevant in the determination of capital outlays, but none has introduced the regulatory constraint to the firm's objective function. Furthermore, there has been no attempt to examine investment expenditures during the period 1954 to 1977, when there were relatively frequent and significant alterations in federal tax policy.

Notes

[1] These are 1977 figures as per the U.S. Bureau of the Census [1978].

[2] Declining production ratios indicate that installed capacity is being used less and less intensively. The implication here is that investment in capacity was exceeding increments in energy requirements from about 1967 to 1975.

CHAPTER III

PREVIOUS STUDIES

Although a great many scholars have devoted time and research to the development and study of theories of investment behavior, relatively few have dealt explicitly with regulated public utilities [1]. Of these studies, only the works of Chenery [1952], Massé [1964], Kisselgoff and Modigliani [1957], Massé and Gibrat [1957], Peck [1974], Sankar [1972], and Rennie [1977] have addressed investment behavior within regulated electric utilities per se. Jorgenson and Handel [1971] examined investment behavior of public utilities including telephone and gas on a quarterly basis. Since Massé and Gibrat concerned themselves with investment behavior in the French electric utility industry, much of their work will not prove applicable in the U.S. regulatory environment.

Chenery [1952] attempted to trace the effect of economies of scale on investment behavior. He showed that given a particular production function and demand forecast there would be an optimum relationship between capacity and output. This optimum would be a function of the rate of increase in demand, the discount rate, the economy of scale, and the planning horizon.

He derived a formula for predicting investment, i.e., the "capacity principle," through successive manipulations of the accelerator principle. His findings reveal that the difference in cyclical behavior between the capacity and accelerator principles depends on: (a) the optimum overcapacity and (b) the reaction coefficient.

He tested the usefulness of his capacity principle on the electric utility industry (one of the six he felt conformed to the assumptions on which the principle is based). He found the capacity principle to be a superior predictor of investment behavior in the industry. His estimates were made using aggregate data from the Federal Power Commission (FPC) for the years 1922 to 1940, an interval of two years for each increment in capacity and ordinary least squares (OLS) estimation procedures.

Concluding that the assumption made about the effect of excess capacity determines the difference between the capacity and accelerator explanations, he suggested that the two principles are suited to different types of industries. The capacity principle he found to be the better tool to apply in oligopolies and industries with high capital intensities, e.g., the electric industry. His results led him to conclude unequivocally that "once overcapacity exists, it is taken into account in further investment and hence should be embodied in whatever equation is used to predict fluctuations in investment" [Chenery 1952, p. 26].

Kisselgoff and Modigliani [1957] hypothesized that the major factor controlling the rate of investment by private electric utilities was their attempt to maintain an optimal rate of utilization of capacity. This optimal rate of capacity utilization was defined as "the maximum number of kWh per year which it is economically desirable to produce for sale per kW of installed capacity under the conditions (technology, pattern of demand, etc.) prevailing at that point in time" [Kisselgoff and Modigliani 1957, p. 366]. Their hypothesis stemmed from the poor results obtained when attempting to explain the investment behavior of electric utilities via interest rates and profits alone [2].

Since electric utilities are firms operating in the absence of direct competition in their service areas and subject to various controls which greatly affect their level of profits, it would not be surprising to find that profits and interest rates alone completely fail to account for their investment behavior. However, Kisselgoff and Modigliani postulated that profits were probably of some significance in the investment process: (a) as a source of investible funds and (b) as a factor reflecting short-run business expectations.

Their final investment function is one in which investment is a function of net income and depreciation, the ratio of kWh demanded to kW of installed capacity required to serve the demand economically, and time; where time is included mainly to reflect the gradual rate of increase in the optimum rate of utilization of capacity over the test period, i.e., 1926-1941.

They assumed that electric utilities adopt investment programs designed to provide a "normal" margin of reserve capacity over and above that needed for current demand. Their contention was that additional investment would be initiated once demand began to diminish a utility's reserves. They further assumed a two-year lag between starts and completions of new generating capacity and estimates were made using aggregate data in private electric utilities for the years 1924-1941 under OLS procedures.

Interestingly, they found interest rates played an insignificant and negative role in their model. This seemingly contradictory behavior was explained as a result of the regulatory environment. Their contention was that a regulating authority would not prevent a company with a balanced capital structure from raising the necessary funds on the

capital market for its legitimate investment, regardless of the level of prevailing interest rates.

They concluded that their model furnished an acceptable explanation of investment decisions in the electric power industry. It is based on a rather simplistic version of the accelerator principle which they modified somewhat by the influence of profits. The accelerator principle played an extensive role relative to that of profits in explaining investment. They determined this to be a result of the institutional conditions under which firms in the electric power industry operate.

Peck [1974] made an analysis of investment in turbogenerator sets over fifteen firms in the electric utility industry for the period 1948-1969. Drawing from Chenery's work, he attempted to study investments made by individual firms with a model of lumpy investments.

Given certain assumptions, he concluded that "the intertemporal cost minimizing strategy is to make an investment when capacity equals demand, wait until demand has grown so that it again equals capacity, make another investment, and so on" [Peck 1974, p. 427]. This is clearly not the method used by electric utilities in expanding their capacity. It neglects not only the long lags between a decision to expand and the final expansion, but a firm's desire to maintain a certain percent of capacity reserves as well. In fact, a firm will never wait until demand equals capacity to make an investment. The very fact that planning and construction take substantial time makes such a policy untenable. Demand would surely exceed capacity at some point during the construction process and the firm would find itself unable to meet demand in its service area.

This model implicitly assumes that turbogenerator sets will be ordered and then installed, with all costs being borne in the installation

period, i.e., the period in which the plant comes on line. Thus, investments are lumpy. Although regulatory boards may often not allow the value of new capacity to enter the rate base until the plant is operating productively [3], a firm's investment in a plant begins with the onset of construction. Once construction is begun, both the high costs of cancellation and the anticipated growth in demand make abandonment of the project an impracticality. Consequently, if changes in a firm's invested capital are to be measured correctly, it seems far more appropriate to look at yearly construction expenditures which, for most electric utilities, involve a continual flow of funds. Under these conditions, investments are not necessarily lumpy [4].

Peck modified a model developed by d'Aspremont, Gabszewicz and Vial [1969] to include variable costs. He then compared results from his model with those from a distributed lag model. He found that although the results from his model were better in the years 1950 to 1960, the distributed lag model performed better in succeeding periods. This is not too surprising since Peck's data sample concentrated specifically on steam generation, ignoring gas turbines, and his model could not account for energy interchanges.

Sankar's model of investment behavior in electric utilities is essentially a revision of the econometric model of investment behavior developed by Jorgenson and Handel [1971]. Using aggregate data from 1946 to 1968, he relaxed two assumptions of the Jorgenson-Handel model to make it more applicable to the electric utility industry. Empirical evidence on economies of scale and elasticities of substitution led him to the conclusion that a CES production function in capital and labor would be a more realistic assumption than the Cobb-Douglas function used

by Jorgenson and Handel. Although his specification of the model was somewhat different than that of Jorgenson and Handel, he still employed a rational distributed lag and used the same estimating procedures, i.e., OLS, ignoring the autocorrelation inherent in the disturbance terms. Since a constraint condition was not satisfied, he imposed the constraint and reestimated the equation [5]. Hence, only two parameters were actually estimated in the final regression and the imposition of the constraint makes one suspicious of those coefficients.

His findings are not too surprising. Using two different user costs of capital (Jorgenson's and his own) he found the elasticity of substitution between capital and labor to be zero in one case and quite small (less than .2) in the other. This is what one would expect given the technology of electricity production.

Rennie [1977] conducted an investigation of the effects of changes in federal tax policy on electric utility investment. He attempted to account for seven tax modifications occurring during the period 1951-1969. The specification of his investment model closely follows that of Jorgenson and Handel [1971]. However, he altered the equation for the user cost of capital. His equation accounts for the changes in federal tax policy incorporated by Hall and Jorgenson [1967] and later by Coen [1968].

His investment function employed a rational distributed lag formulation and relatively long lags were permitted. The iterative procedure developed by Cochrane and Orcutt [1949] was used to avoid inconsistent estimates due to serial correlation. The final equation explained 93.5 percent of the variability in gross investment and implied an average lag between a change in desired capital stock and completion of the investment project of 8.3 years.

He found that accelerated depreciation, federal tax cuts, and the investment tax credit (ITC) all caused a reduction in the user cost of capital services. This resulted in increased production plant expenditures and an increase in the capital stock of privately owned Class A and B electric utilities [6].

His sample ignored many investor-owned electric utilities that did not meet FPC standards for A and B utilities. This certainly biases his results since the firms ignored are uniformly smaller, with lower profit margins. Further, the FPC periodically changes its standards for electric utilities classified as A and B privates. It is not clear that Rennie took this into account.

Using a Cobb-Doublas production function, his final equation specifies investment in period t, I_t, as dependent upon changes in desired capital stock, K*, in periods t-3, t-5, and t-8; investment for expansion, I^{ε}, in period t-1; and actual capital stock, K, in period t-1. The constant term in his regression is -2499.47 [7]. It is not significant at even the .10 level and offers no intuitive appeal. Rennie wisely avoids its discussion, but its presence serves to leave his results open to doubt.

Of the studies surveyed, only Peck used firm data. His data sample was too restrictive to adequately explain investment in the 1960's and he found that a distributed lag function performed better than his model for years following 1960. The others all used aggregate data from years prior to 1969. It is not clear that Chenery even separated investor-owned utilities from the rest of the industry.

Kisselgoff and Modigliani included a time variable in order to account for gradually increasing rates of utilization between 1926 and and 1941. As Table 1 demonstrates, such was no longer the case between 1958 and 1975. Sankar failed to account for the long lags which characterize industry expansion and imposed a constraint which his equation did not satisfy. Thus, his results are questionable.

Rennie's model had good explanatory power but ignored part of the industry, i.e., those firms not classified as A or B privates by the FPC. His lag specifications seemed reasonable, but the presence of an unexplained intercept term which is large, negative and insignificant makes the rest of his results somewhat suspicious.

Finally, there is an underlying defect in all these studies. They fail to consider the implications of rate-of-return regulation in the formulation of their models. It is with this and other oversights of previous models in mind that this study will proceed.

Notes

[1] Studies of regulated public utilities include: Klein [1951], Chenery [1952], Eisner [1960], Koyck [1963], Kisselgoff and Modigliani [1957], Massé and Gibrat [1957], Jorgenson and Handel [1971], Peck [1974], Sankar [1972], and Rennie [1977].

[2] Realized profits were utilized due to the frequent suggestion that they can approximate the productivity of capital.

[3] There is evidence that this is changing as more and more commissions allow the inclusion of construction work in progress (CWIP) in the firm's rate base.

[4] Even though lead times have increased since 1960, the bulk of expenditures are still incurred in the last few years of construction.

[5] Since his final equation,

$$\Delta \ln K_t = 0.04818\, \Delta \ln (p/c_1)_{t-2} + 0.18499\, \Delta \ln Q_{t-2} + 0.99306\, \Delta \ln K_{t-1} - 0.28984\, \Delta \ln K_{t-2},$$

did not meet the condition that $-\hat{\omega}_2 \geq -\hat{\omega}_1^2/4$, Sankar reestimated the regression using the unconstrained estimate of $\omega_1 = -0.99306$ and $\hat{\omega}_2$ as $-\hat{\omega}_1^2/4 = 0.24654$. The resulting regression is:

$$\Delta \ln K_t - 0.99306 \Delta \ln K_{t-1} + 0.24654 \Delta \ln K_{t-2} = 0.04643 \Delta \ln (p/c_1)_{t-2} + 0.18499 \Delta \ln Q_{t-2}.$$

See Jorgenson and Stephenson [1967] for a detailed discussion of this procedure and Griliches [1967] for a systematic development of the constraints implied by Sankar's rational distributed lag formulation.

[6] In 1969, the FPC defined Class A electric utilities as those having annual electric operating revenues of $2.5 million or more and Class B utilities as those with annual electric operating revenues of $1.0 million or more but less than $2.5 million. See U.S. Federal Power Commission [1969].

[7] Rennie states that he measured investment by construction expenditures as per Moody's Investor Service, Inc. Since he did not report his data, it is not clear whether this reflects thousands or millions of constant dollars.

CHAPTER IV

A MODEL OF INVESTMENT BEHAVIOR

The User Cost of Capital

A model of investment behavior for regulated electric utilities must incorporate the constraints imposed by the regulating authority. Under rate-of-return regulation, the profit-maximizing monopolist must satisfy the quantity demanded at the price set while not earning a return on its capital in excess of s, the allowable rate of return. Jorgenson and Handel [1971] incorporated the former constraint in their model, but failed to account for the latter. Thus, their formulation of investment behavior is not quite correct for regulated electric utilities, though it may suffice for other regulated industries not subject to a rate-of-return constraint.

Their model suggests that the rental price of capital, c_t, adjusted for the U.S. tax structure will be

$$c_t = q_t\{\frac{1-u_t v_t}{1-u_t}\ \delta + \frac{1-u_t w_t}{1-u_t}\ r_t - \frac{1-u_t x_t}{1-u_t}\ \frac{\dot{q}_t}{q_t}\},$$

where δ = the rate of replacement (or depreciation rate);

r_t = the interest rate in time t;

q_t = the price of I in period t;

I_t = investment in period t;

v_t, w_t, & x_t represent the proportions of depreciation, cost of capital and capital loss which may be charged against revenue less outlay on current account in measuring income for tax purposes;

$\dot{q}_t = \frac{dq}{dt}$;

$-\frac{\dot{q}_t}{q_t}$ = the rate of capital loss; and

u_t = the rate of taxation of net income, defined for tax purposes [1].

Since c_t figures prominently in their econometric model of investment behavior, it should be adjusted to account for the rate-of-return constraint imposed by the regulatory authority. The derivation of an adjusted c_t closely follows that of Jorgenson and Handel except for the inclusion of the regulatory constraint and the addition of fuel as an input to the productive process.

A Reformulation of the User Cost of Capital

Let $Z(t) = PQ - wL - fF - qI$

$$T(t) = u(t)\{PQ - wL - fF - q[v(t)\delta + w(t)r - x(t)\frac{\dot{q}}{q}]K\}$$

(1) $$PV = \int_0^\infty e^{-rt}[Z(t) - T(t)]dt.$$

where $v(t)$, $w(t)$ & $x(t)$ represent the proportions of depreciation, cost of capital and capital loss which may be charged against revenue less outlay on current account in measuring income for tax purposes;

Q, L, I, F & K = output, labor, investment, fuel and capital, respectively;

P, w, q & f = the prices of Q, L, I and F, respectively;

$T(t)$ = the amount of direct tax assessed in period t;

$u(t)$ = the rate of taxation of net income, defined for tax purposes; and

$-\frac{\dot{q}}{q}$ = the rate of capital loss.

(2) $\dot{K} = I - \delta K; \; \dot{K} = \frac{dK}{dt}$.

Equation (2) is formulated on the assumption that replacement is proportional to capital stock, K. It states that the time rate of change of capital stock is equal to investment less replacement.

Since the regulated electric utility must satisfy the quantity demanded at the price set, the quantity of output, Q, is determined by the consuming public. This constraint takes the form:

(3) $Q = Q_o(P_o)$,

where Q_o is the level of output demanded by the consuming public in the firm's service area.

Additionally, the appropriate regulatory authority determines a fair rate of return, s, which the firm may not exceed. Thus, the rate-of-return constraint will take the usual form.

(4) $PQ - wL - fF \leq sK$,

where it is assumed $r < s < z$; z being the rate of return the profit-maximizing monopolist would earn in the absence of regulation.

Finally, the utility is constrained by its production function:

(5) $Q = Q(K,L,F)$ [2],

where $Q > 0$ and $Q(K,L,0) = Q(K,0,F) = Q(0,L,F) = 0$, and the maximization problem becomes:

(6) Maximize $PV = \int_0^\infty \{e^{-rt} [Z(t) - T(t)]\}dt$

Subject to: $\dot{K} = I - \delta K$

$Q = Q(K,L,F)$

$Q = Q_o$

$PQ - wL - fF \leq sK.$

Substituting $\dot{K} + \delta K$ for I and $Q(K,L,F)$ for $Q = Q_o$ yields the following Lagrangian for maximization of present value:

$$(7) \qquad \mathcal{L} = \int_0^\infty \{e^{-rt}\{[PQ(K,L,F) - wL - fF - q\dot{K} - q\delta K]$$

$$-u(t)[PQ(K,L,F) - wL - fF - q(v(t)\delta + w(t)r - x(t)\frac{\dot{q}}{q})K]\} + e^{-rt}\lambda(t)[PQ(K,L,F) - wL - fF - sK]\}dt,$$

$$= \int_0^\infty g(t)dt.$$

Since the firm is a monopolist, the market demand function may take the general form:

$$(8) \qquad P = P(Q), \ \frac{\partial P}{\partial Q} < 0;$$

and the problem, (6), has a solution characterized by the following first-order and Kuhn-Tucker conditions [3]:

$$(9a) \quad \frac{\partial g}{\partial L} = e^{-rt}[1-u(t) + \lambda(t)]\frac{\partial Q}{\partial L}[1-\frac{1}{\eta}] P - e^{-rt}[1-u(t) + \lambda(t)]w = 0,$$

$$(9b) \quad \frac{\partial g}{\partial K} - \frac{d}{dt}\frac{\partial g}{\partial \dot{K}} = e^{-rt}[1-u(t) + \lambda(t)]\frac{\partial Q}{\partial K}[1 - \frac{1}{\eta}] P$$

$$-e^{-rt} q\{[1-u(t)v(t)]\delta + [1-u(t)w(t)]r$$

$$- [1-u(t)x(t)]\frac{\dot{q}}{q}\} - e^{-rt}\lambda(t)s = 0,$$

$$(9c) \quad \frac{\partial g}{\partial F} = e^{-rt}[1-u(t) + \lambda(t)]\frac{\partial Q}{\partial F}[1-\frac{1}{\eta}] P - e^{-rt}[1-u(t) + \lambda(t)]f = 0,$$

(9d) $$\frac{\partial g}{\partial \lambda(t)} = e^{-rt}\,[PQ(K,L,F) - wL - fF - sK] \leq 0,$$

and $\lambda(t) \geq 0$, $\lambda(t)\ \dfrac{\partial g}{\partial \lambda(t)} = 0$;

where $\eta = -\dfrac{\partial Q}{\partial P}\ \dfrac{P}{Q}$ and $\dfrac{1}{\eta} = -\ \dfrac{\partial P}{\partial Q}\dfrac{Q}{P}$

Dividing (9b) by (9a) yields:

(10) $$\frac{\frac{\partial Q}{\partial K}}{\frac{\partial Q}{\partial L}} = \frac{\partial L}{\partial K} = \frac{q\{[1-u(t)v(t)]\delta+[1-u(t)w(t)]r - [1-u(t)x(t)]\ \frac{\dot{q}}{q}\} + \lambda(t)s}{[1-u(t) + \lambda(t)]\ w}$$

Equation (10) will reduce to Jorgenson's formula only if $\lambda(t) = 0$, i.e., only if the regulatory constraint is ineffective. Then we would have:

(11) $$\frac{\frac{\partial Q}{\partial K}}{\frac{\partial Q}{\partial L}} = \frac{\partial L}{\partial K} = \frac{q\{[1-u(t)v(t)]\delta+[1-u(t)w(t)]r - [1-u(t)x(t)]\ \frac{\dot{q}}{q}\}}{[1-u(t)\ ]\ w}$$

and Jorgenson's user cost of capital, c_t, would follow.

Solving (9a), (9b), and (9c) simultaneously yields:

(12) $$\lambda(t) = \frac{[1-u(t)]\ [w-f-(1-\frac{1}{\eta})P(\frac{\partial Q}{\partial L} - \frac{\partial Q}{\partial K} - \frac{\partial Q}{\partial F})]}{(1-\frac{1}{\eta})\ P\ (\frac{\partial Q}{\partial L} - \frac{\partial Q}{\partial K} - \frac{\partial Q}{\partial F}) - w + s + f} - \frac{q\{[1-u(t)v(t)]\ \delta + [1-u(t)w(t)]\ r - [1-u(t)x(t)]\frac{\dot{q}}{q}\}}{(1-\frac{1}{\eta})\ P\ (\frac{\partial Q}{\partial L} - \frac{\partial Q}{\partial K} - \frac{\partial Q}{\partial F}) - w + s + f},$$

which when substituted back into (10) yields:

(13) $$\frac{\partial L}{\partial K} = \frac{\frac{\partial Q}{\partial K}\ (1 - \frac{1}{\eta})\ P}{w}.$$

From the first-order and Kuhn-Tucker conditions, it can be shown that equation (13) reduces to an identity. Thus, a method must be employed which will allow $\lambda(t)$ to be estimated from observable variables.

Determination of $\lambda(t)$ significantly different from zero would imply that the effectiveness of the regulatory constraint should be accounted for in equation (10). Jorgenson's user cost of capital adjusted to reflect the effectiveness of rate-of-return regulation on electric utilities then becomes:

$$(14) \quad c_{rt} = \frac{q\{[1-u(t)v(t)]\delta + [1-u(t)w(t)]r - [1-u(t)x(t)]\frac{\dot{q}}{q}\} + \lambda(t)s}{[1-u(t) + \lambda(t)]w}$$

A Model for Estimating $\lambda(t)$

Following Cowing [1975], $\lambda(t)$ is assumed to vary across firms and, hence, across observations. It is intrinsically unobservable such that an estimation procedure may be used which permits λ to be estimated without requiring observations on λ. Cowing's profit function approach offers an econometric framework which enables both of these problems to be handled simultaneously.

A separate estimate of λ may be made for each regulated utility during the period. The estimates of λ thus obtained may then be substituted back into equation (14) to determine estimates of c_{rt}. As has already been discussed, c_{rt} is the appropriate rental price of capital to use in Jorgenson's econometric model of investment behavior when analyzing regulated electric utilities.

Utilizing the so-called unit-output-price (UOP) or normalized profit function developed by Lau [1969] and a revised version of Hotelling's

lemma [4], the profit function approach may be extended to the case of a regulated profit-maximizing firm.

Letting * denote profit-maximizing or optimal values, the Lagrangian expression for the problem of a profit-maximizing firm subject to rate-of-return regulation becomes:

$$(15)\quad \mathcal{L}^* = Q[K^*(w',i',s'), L^*(w',i',s')] - w'L^*(w',i',s') - i'K^*(w',i',s') = \Pi^*(w',i',s'),$$

where all variables are as defined previously and where

$w' = \frac{w}{P}$;

$i' = \frac{i}{P}$, i = the rental price of capital;

$s' = \frac{s}{P}$;

$\Pi^*(w',i',s') = \Pi^*$ = maximized profit and

$K^*(w',i',s') = K^*$ and $L^*(w',i',s') = L^*$ which are the profit-maximizing input demands.

Equation (15) holds because $\lambda[Q(K,L) - i'L - s'K] = 0$, when evaluated at the optimal values for K, L and λ.

Cowing's revised version of Hotelling's lemma for the special case of a profit-maximizing firm subject to regulation is as follows [Cowing 1975, p. 11]:

$$(16)\quad \frac{\partial \Pi^*}{\partial w'} = \frac{\partial \mathcal{L}^*}{\partial w'} = -(1-\lambda^*)L^*,$$

$$(17)\quad \frac{\partial \Pi^*}{\partial i'} = \frac{\partial \mathcal{L}^*}{\partial i'} = -K^*,$$

$$(18)\quad \frac{\partial \Pi^*}{\partial s'} = \frac{\partial \mathcal{L}^*}{\partial s'} = \lambda^* K^*.$$

Dropping the * notation for convenience; defining $\frac{\partial \Pi^*}{\partial w'} = \Pi_{w'}$, $\frac{\partial \Pi^*}{\partial i'} = \Pi_{i'}$ and $\frac{\partial \Pi^*}{\partial s'} = \Pi_{s'}$; and solving equations (16) - (18) for λ yields:

$$\lambda = - \frac{\Pi_{s'}}{\Pi_{i'}}, \tag{19}$$

such that estimates of λ for each observation may be computed from the estimated parameters of the profit function.

Eliminating λ, which is not observable, and including the UOP profit function as a separate equation allows equations (16) - (18) to be expressed equivalently as:

$$\begin{aligned} \Pi &= \Pi(w',i',s') \\ -L &= \frac{\Pi_{w'}\,\Pi_{i'}}{\Pi_{i'} + \Pi_{s'}} \\ -K &= \Pi_{i'} \end{aligned} \tag{20}$$

which is a general reduced-form econometric scheme for the regulated firm with all equations expressed in the observable prices w', i' and s'.

Since the generation of electricity requires three main inputs, capital, labor and fuel, (20) must be extended to include fuel (F) and its normalized prices (f'). The resulting system is:

$$\begin{aligned} \Pi &= \Pi(f',w',i',s') \\ -F &= \frac{\Pi_{f'}\,\Pi_{i'}}{\Pi_{i'} + \Pi_{s'}} \\ -L &= \frac{\Pi_{w'}\,\Pi_{i'}}{\Pi_{i'} + \Pi_{s'}} \\ -K &= \Pi_{i'} \end{aligned} \tag{21}$$

and the equation for λ remains the same, i.e., (19).

Adopting a quadratic specification of the regulated profit function, Π, yields:

(22) $$\Pi = \beta_0+\beta_1 f+\beta_2 w+\beta_3 i+\beta_4 s+\beta_5 \frac{f^2}{2} + \beta_6 \frac{w^2}{2} + \beta_7 \frac{i^2}{2} + \beta_8 \frac{s^2}{2}$$

$$+ \beta_9(fw)+\beta_{10}(fi)+\beta_{11}(fs)+\beta_{12}(wi)+\beta_{13}(ws)+\beta_{14}(is),$$

where all input prices have been normalized in terms of the output price [5].

Noting that the partial derivatives of (22) are:

$$\Pi_f = \beta_1+\beta_5 f+\beta_9 w+\beta_{10} i+\beta_{11} s,$$

(23) $$\Pi_w = \beta_2+ \beta_9 f+\beta_6 w+\beta_{12} i+\beta_{13} s,$$

$$\Pi_i = \beta_3 +\beta_{10} f+\beta_{12} w+\beta_7 i+\beta_{14} s, \text{ and}$$

$$\Pi_s = \beta_4+\beta_{11} f+\beta_{13} w+\beta_{14} i+\beta_8 s,$$

equations in (22) and (23) may be substituted into (21). With the addition of classical additive disturbance terms to each equation, we obtain:

$$\Pi = \beta_0+\beta_1 f+\beta_2 w+\beta_3 i+\beta_4 s+\beta_5 \frac{f^2}{2} + \beta_6 \frac{w^2}{2} + \beta_7 \frac{i^2}{2} + \beta_8 \frac{s^2}{2} +$$

$$\beta_9(fw)+\beta_{10}(fi)+\beta_{11}(fs)+\beta_{12}(wi)+\beta_{13}(ws)+\beta_{14}(is)+\varepsilon_1$$

(24) $$-F = \frac{(\beta_1+\beta_5 f+\beta_9 w+\beta_{10} i+\beta_{11} s)(\beta_3+\beta_{10} f+\beta_{12} w+\beta_7 i +\beta_{14} s)}{(\beta_3+\beta_4)+(\beta_{10}+\beta_{11})f+(\beta_{12}+\beta_{13})w+(\beta_7+\beta_{14})i+(\beta_{14}+\beta_8)s} +\varepsilon_2$$

$$-L = \frac{(\beta_2+\beta_9 f+\beta_6 w+\beta_{12} i+\beta_{13} s)(\beta_3+\beta_{10} f+\beta_{12} w+\beta_7 i+\beta_{14} s)}{(\beta_3+\beta_4)+(\beta_{10}+\beta_{11})f+(\beta_{12}+\beta_{13})w+(\beta_7+\beta_{14})i+(\beta_{14}+\beta_8)s} + \varepsilon_3$$

$$-K = \beta_3+\beta_{10} f+\beta_{12} w+\beta_7 i+\beta_{14} s+\varepsilon_4,$$

which is an estimable system of reduced-form equations.

Since regulated electric utilities are apt to come from different states with significant variations in regulatory procedures, individual λ's must be estimated for each of the j firms, j = 1, 2, 3, ... n, under consideration. Thus, a $\lambda(t)$ must be obtained for each utility in the sample. It then remains to test the null hypothesis $\lambda_j(t) = 0$.

Specification of a Model of Investment Behavior

The level of output set by the consuming public, Q_o, is equal to the actual level of output, Q, since regulated electric utilities are legally obligated to meet demand in the areas in which they have a franchise. The desired level of capital, K*, is determined from the marginal productivity of capital, while the actual capital stock, K, is determined by past accumulation.

For a CES production function of the following form:

$$(25) \qquad Q = A \left(\alpha_1 K^{-\rho} + \alpha_2 L^{-\rho} + \alpha_3 F^{-\rho}\right)^{-\frac{k}{\rho}}$$

where A is a (neutral) efficiency parameter, α_i is the distribution parameter, k is the scale parameter and ρ is the substitution parameter; it can be shown that all partial elasticities of substitution are equal to:

$$(26) \qquad \sigma = \frac{1}{1 + \rho} .$$

For an electric utility, the value of labor is small in proportion to the value of output. The value of fuel, however, is steadily composing a larger and larger proportion of output value. Hence, this model will concentrate on a trade-off between capital and fuel.

The CES production function will take the form:

$$(27) \qquad Q = A \left[\alpha K^{-\rho} + (1-\alpha)F^{-\rho}\right]^{-\frac{k}{\rho}},$$

where all parameters are as previously defined and the following restrictions apply:

$$\rho > -1,\ \sigma \geq 0,\ A > 0,\ 0 < \alpha < 1 \text{ and } k > 0.$$

Calculation of the marginal product of capital yields:

$$(28) \qquad K^* = \left(\alpha k A^{-\rho/k}\right)^{1/(1+\rho)} Q^{(k+\rho)/k(1+\rho)} \left(\frac{P}{c}\right)^{1/(1+\rho)},$$

$$= \text{const } Q^{(k+\rho)/k(1+\rho)} \left(\frac{P}{c}\right)^{1/(1+\rho)},$$

where P is the price of output, and $c = c_{rt}$.

Recalling that $\sigma = \frac{1}{1+\rho}$, equation (28) may be written as:

$$(29) \qquad K^* = \text{const } Q^{[\sigma + (1-\sigma)/k]} \left(\frac{P}{c}\right)^{\sigma},$$

which is of the same form as that derived by Jorgenson and Handel if $\sigma = 1$.

The theory of investment behavior used herein will correspond to a distributed lag function in levels of capital stock and desired levels of capital stock. The relationship between the changes in these two levels of capital stock is assumed to be of the form [6]:

$$(30) \qquad \ell n(K_{t+1}/K_t) = \mu_o(\ell n K^*_t - \ell n K^*_{t-1}) + \mu_1(\ell n K^*_{t-1} - \ell n K^*_{t-2}) + \ldots$$

Or using the lag operator, L, defined by $Lx_t = x_{t-1}$, for any sequence $\{x_t\}$, (30) may be written as:

$$(31) \qquad \ln(K_{t+1}/K_t) = [\mu_o + \mu_1 L + \mu_2 L^2 + \ldots] \quad [\ln K^*_t - \ln K^*_{t-1}]$$

$$= \mu(L) \; [\ln K^*_t - \ln K^*_{t-1}] \; ,$$

where $\mu(L)$ is a power series in the lag operator, $\mu(L) = \mu_o + \mu_1 L + \ldots$. Under the assumption that the sequence of coefficients μ_τ of the distributed lag function has a rational generating function, equation (31) may be written as:

$$(32) \qquad \ln(K_{t+1} / K_t) = \frac{\gamma(L)}{\omega(L)} \; [\ln K^*_t - \ln K^*_{t-1}] \; ,$$

where $\omega(L)$ and $\gamma(L)$ are polynomials in the lag operator; $\omega(L) = 1 + \omega_1 L + \omega_2 L^2 + \ldots + \omega_n L^n$, and $\gamma(L) = \gamma_o + \gamma_1 L + \gamma_2 L^2 + \ldots + \gamma_m L^m$. The coefficients $\{\omega_\tau, \gamma_\tau\}$ determine the coefficients $\{\mu_\tau\}$ of the distributed lag function [7].

Equation (32) may alternatively be written as:

$$(33) \qquad \omega(L) \; \Delta \ln K_t = \gamma(L) \; \Delta \ln K^*_t \; ;$$

or, expanding $\omega(L)$ and $\gamma(L)$ as:

$$(34) \qquad \Delta \ln K_t + \omega_1 \Delta \ln K_{t-1} + \ldots + \omega_n \Delta \ln K_{t-n} =$$

$$\gamma_0 \Delta \ln K^*_t + \gamma_1 \Delta \ln K^*_{t-1} + \ldots + \gamma_m \Delta \ln K^*_{t-m} .$$

After substituting equation (29) into equation (34) and adding an error term, ν_t, the final distributed lag function may be written:

$$(35) \qquad \Delta \ln K_t = \sum_{i=0}^{m} [\gamma_{Qi} \Delta \ln Q_{t-i} + \gamma_{Pi} \Delta \ln (\frac{P}{c})_{t-i}] - \sum_{j=1}^{n} \omega_j \Delta \ln K_{t-j} + \nu_t .$$

Jorgenson derived several restrictions for the parameters of the lag polynomials. For the special case of $\omega(L)$ of order 2, to satisfy the condition that the coefficients of the distributed lag function be non-negative, it is required that the leading coefficients of $\gamma(L)$ be non-negative, and that $-4\omega_2 \geq -\omega_1^2$. The distributed lag function is a stable difference equation if the sum of ω_1 and ω_2 is less than one [8].

The lag polynomials in equation (35) are subject to the same restrictions as those imposed by Jorgenson, but the model is superior to his at least for the case of electric utilities. It permits one to estimate separately the long-run elasticites of capital stock with respect to relative price and output. An implied point estimate of the returns-to-scale parameter, k, may be derived, and it incorporates the rate-of-return constraint into the firm's objective function.

Notes

[1] This equation is developed in detail in Jorgenson and Stephenson [1967].

[2] It should be noted that this constraint neglects the fact that a firm might engage in some form of power pooling. However, it can be shown that the inclusion of an adjustment to account for this possibility will not affect the results of this analysis, i.e., equation (14).

[3] A mathematical programming analysis offers a natural way of estimating $\lambda(t)$. Thus, one topic for future research would appear to be addressing the problem in such a framework.

[4] See Hotelling [1932].

[5] This specification may be interpreted as a second-order Taylor series approximation to the true underlying profit function.

[6] See Eisner and Nadiri [1968].

[7] Jorgenson [1966] demonstrated that an arbitrary distributed lag function may be approximated to any desired degree of accuracy by a rational distributed lag function.

[8] Griliches [1967] has shown that the following restrictions must be met when $\omega(L) = 1 - \omega_1 L - \omega_2 L^2$:

$$0 < \omega_1 < 2$$

$$-1 < \omega_2 < 1$$

$$1 - \omega_1 - \omega_2 > 0$$

and $$\omega_1^2 + 4\omega_2 \geq 0.$$

Similarly, it can be shown that when $\omega(L) = 1 + \omega_1 L + \omega_2 L^2$, the range of interest will be given by:

$$0 > \omega_1 > -2$$

$$1 > \omega_2 > -1$$

$$1 + \omega_1 + \omega_2 > 0$$

and $$\omega_1^2 - 4\omega_2 \geq 0.$$

CHAPTER V

METHODOLOGY AND DATA

The Effects of Regulation

Ideally, one could follow Cowing [1975], use micro data and a unit-output-price (UOP) or normalized profit function [1] to obtain estimates of $\lambda_j(t)$. However, firm data are not available, reliable, or complete enough to enable such an estimation process. Research revealed that the Edison Electric Institute (EEI) maintains accurate information on an industry-wide basis. Hence, it was decided that aggregate industry data should be employed to generate a proxy for $\lambda(t)$, the measure of regulatory effectiveness.

Joskow's data [2] indicated that the number of firms filing for rate increases rose whenever the aggregate rate of return in the industry fell. That is, utilities instituted regulatory reviews when they found their own rate of return falling below the market rate of return on capital. One may infer that companies increasingly file rate-of-return reviews as the regulatory constraint, equation (4), becomes more effective, or tighter. In light of this framework, the percent of firms filing rate-of-return reviews offers a suitable proxy for measuring the intensity of regulatory pressure in any particular year [3].

Drawing upon the work of Bischoff [1969] and Ando, Modigliani, Rasche, and Turnovsky [1974] who estimated the user cost of capital simultaneously with the coefficients of their investment functions, the following formulation was derived:

(36) $$\hat{R}_t = RA_t + \alpha\pi_t ,$$

where RA_t = the user cost of capital in the industry in period t,

π_t = the percent of firms filing for rate increases in period t, and

$\hat{R}_t$ = a proxy for the user cost of capital adjusted for the effects of regulation.

Varying α generates several series of $\hat{R}_t$. The values of $\hat{R}_t$ so obtained may then be used in the investment function, equation (35), as a proxy for c_{rt}, the user cost of capital adjusted for the effects of regulation. Since the value of α yielding the best fit for equation (35) is assumed to be indicative of the effect of rate-of-return regulation on the user cost of capital in the industry, the coefficients for (35) and (36) can be estimated simultaneously.

Tax Policy and the Cost of Capital Services

The price of new capital goods, q, must equal the present value of future rentals which is affected by the tax structure. Thus, the implicit rental value of capital services becomes:

(37) $$RA_t = \frac{(1 - k_t)(1-u_t z_t)}{(1 - u_t)} q_t \ (r_t + \delta_t) ,$$

where z_t = the present value of the depreciation deduction on one dollar's investment in period t,

k_t = the investment tax credit rate permitted in period t,

r_t = the average aggregate weighted cost of capital [4],

and all other variables are as previously defined [5]. In accordance with

general regulatory practice, the average weighted cost of capital is taken to be the proper measure for regulated electric utilities [6].

Equation (37) is appropriate for 1962 and 1963 as it assumes the depreciation base is reduced by the amount of the tax credit. The Long Amendment to the Revenue Act of 1962 required electric utilities to deduct the tax credit from allowable depreciation. However, the Long Amendment was repealed in 1964. This caused equation (37) to become:

$$RA_t = \frac{(1 - k_t - u_t z_t)}{(1 - u_t)} q_t \, (r_t + \delta_t) \; , \tag{38}$$

reflecting the fact that for 1964 and later years, the depreciation base was not reduced by the amount of the tax credit.

The Internal Revenue Code of 1954 allowed three depreciation formulae for tax purposes: straight-line, sum-of-the-years-digits, and double-declining-balance. To obtain the appropriate cost of capital services for each formula, it is necessary to calculate the present value of the depreciation deduction for each one [7].

Prior to the Revenue Act of 1954, only straight-line depreciation was allowed for tax purposes. Under this method, the deduction is constant over a period of length τ, the lifetime for tax purposes. If t is the age of the assets, then the depreciation deduction in time t is:

$$D(t) = \frac{1}{\tau} \, , \quad \forall \quad 0 \leq t \leq \tau \; ; \tag{39}$$

with present value:

$$(40) \quad z = \int_o^{\tau} \frac{e^{-rt}}{\tau} dt, \quad = \frac{1}{r\tau}(1 - e^{-r\tau}).$$

For sum-of-the-years-digits, the deduction declines linearly over the tax life and is given by:

$$(41) \quad D(t) = \frac{2(\tau - t)}{\tau^2}, \quad o \leq t \leq \tau;$$

with present value:

$$(42) \quad z = \int_o^{\tau} e^{-rt} \frac{2(\tau - t)}{\tau^2} dt, \quad = \frac{2}{r\tau}\{1 - \frac{1}{r\tau}(1 - e^{-r\tau})\}.$$

Tax provisions for double-declining-balance depreciation are more complicated. A firm may switch to straight-line depreciaton at any time. If the switchover point is denoted τ^*, the double-declining-balance depreciation formula is:

$$(43) \quad D(t) = \begin{cases} \frac{2}{\tau} e^{-(2/\tau)t}, & 0 \leq t \leq \tau^*, \\ \frac{1 - e^{-(2/\tau)\tau^*}}{\tau - \tau^*}, & \tau^* \leq t \leq \tau; \end{cases}$$

with present value:

$$(44) \quad \begin{aligned} z &= \frac{2}{\tau} \int_o^{\tau^*} e^{-(r + (2/\tau))t} dt + \frac{1 - e^{-(2/\tau)\tau^*}}{\tau - \tau^*} \int_{\tau^*}^{\tau} e^{-rt} dt, \\ &= \frac{\frac{2}{\tau}}{r + \frac{2}{\tau}} \{1 - e^{-(r\tau^* + (2/\tau)\tau^*)}\} \\ &+ \frac{e^{-(2/\tau)\tau^*}}{r(\tau - \tau^*)} \{e^{-r\tau^*} - e^{-r\tau}\}. \end{aligned}$$

The switchover point which maximizes z is $\tau^* = \tau/2$. Representative values of the present value of the deduction for each of the three methods are given given in Table 2.

The adoption of accelerated methods for computing depreciation in 1954 involved a change from straight-line depreciation to either sum-of-the-years-digits or double-declining-balance formulae. Previous studies have assumed that companies would choose the method of depreciation which had the largest present value. As Table 2 demonstrates, sum-of-the-years-digits does offer a slight advantage over double-declining-balance for the range of lifetimes and interest rates with which this study is concerned. However, in a sample survey for the year 1965, Brigham [1966] found that 75.4 percent of the electric companies using accelerated depreciation methods adopted double-declining-balance. The remaining 24.6 percent employed sum-of-the-years-digits. This analysis considers both methods.

Table 3 gives the present values of the depreciation deduction for both accelerated methods. The figures used in the calculations are discussed in the following section. Although sum-of-the-years-digits renders higher values in every year, the final investment function is not appreciably affected by the depreciation method employed. In fact, the double-declining-balance deduction leads to slightly better results than sum-of-the-years-digits. Since double-declining-balance is more representative of industry practice, it is assumed that the 1954 tax revision resulted in a change from straight-line to double-declining-balance depreciation methods.

The Data

The model of investment behavior developed in Chapter IV was applied to annual data on privately owned electric utilities in the United States.

TABLE 2

PRESENT VALUES OF DEPRECIATION DEDUCTIONS

Lifetime	Interest Rate	Depreciation Method: Straight Line	Sum-of-the-Year-Digits	Double-Declining-Balance
15	.04	.75198	.82673	.79504
15	.08	.58234	.69610	.65064
15	.12	.46372	.59586	.54622
25	.04	.63212	.73576	.69350
25	.08	.43233	.56767	.51788
25	.12	.31674	.45551	.40968
35	.04	.53815	.65979	.61215
35	.08	.33543	.47470	.42769
35	.12	.23453	.36451	.32687

Note: These figures are comparable to those of Davidson and Drake [1961], Davidson and Drake [1964], Hall and Jorgenson [1967], and Rennie [1977].

TABLE 3

PRESENT VALUES OF DEPRECIATION DEDUCTIONS BASED ON DATA EMPLOYED IN THIS STUDY

Year	Sum-of-the-Years-Digits	Double-Declining-Balance
1954	0.726362	0.683267
1955	0.724420	0.681158
1956	0.712550	0.668310
1957	0.694715	0.649152
1958	0.719043	0.675329
1959	0.718139	0.674349
1960	0.717096	0.673221
1961	0.742240	0.700590
1962	0.739004	0.697048
1963	0.746804	0.705594
1964	0.737868	0.695806
1965	0.732030	0.689435
1966	0.692409	0.646687
1967	0.676399	0.629662
1968	0.669755	0.622639
1969	0.644188	0.595844
1970	0.602712	0.553168
1971	0.618832	0.569638
1972	0.602274	0.553180
1973	0.580609	0.530829
1974	0.494248	0.446246
1975	0.496701	0.448590
1976	0.525624	0.476481
1977	0.538554	0.489104

Several sources including publications of the Edison Electric Institute (EEI), the Federal Energy Regulatory Commission (FERC), the Federal Power Commission (FPC), and Moody's Investor Service, Inc. [8], provided the necessary data. Regressions based on the lag specification in equation (35) were fitted to data for the period 1963-1977. Data for the years 1954-1962 served to measure lagged variables.

Since the capital stock at any point in time is not homogeneous in age or type of physical equipment, a methodology was needed to account for the stream of net additions over time which the capital stock represents. This study employed an adjusted Handy-Whitman index to deflate the annual net investment in capital stock [9]. The following equation furnished an acceptable estimate of the 1954 capital stock in constant (1971) dollars [10]:

$$(45) \qquad K_t = \frac{AK_t}{\sum_{i=1}^{15} \frac{i}{120} HWI_j} ,$$

where $t = 1954$,

$j = 1938 + i$,

K_t = the reconstructed capital stock in 1954,

AK_t = the actual (unreconstructed) capital stock in 1954, and

HWI_j = the adjusted Handy-Whitman index for year j.

The depreciation rate, δ , was calculated using EEI's data on depreciation expense and electric utility plant. The ratio of annual depreciation expense to average annual electric utility plant provided an appropriate measure of the actual rate of replacement. These figures are consistent with those of Jorgenson and Handel [1971] and those of Rennie [1977]. They are presented in Table 4.

TABLE 4

INVESTOR-OWNED ELECTRIC UTILITIES:
VALUE OF CAPITAL STOCK, DEPRECIATION RATE,
GROSS INVESTMENT, AND CONSTRUCTION COST INDEX

Year	Value of Capital Stock (1971 Dollars) (Millions)	Depreciation Rate	Gross Investment (Current Dollars) (Millions)	Construction Cost Index (1971=1.0)
1954	56,340	0.0245	2,835	0.562
1955	59,941	0.0249	2,719	0.580
1956	63,081	0.0254	2,910	0.631
1957	66,035	0.0252	3,679	0.671
1958	69,783	0.0251	3,764	0.688
1959	73,431	0.0248	3,383	0.701
1960	76,373	0.0252	3,331	0.699
1961	79,156	0.0253	3,256	0.684
1962	81,850	0.0259	3,154	0.691
1963	84,237	0.0264	3,319	0.690
1964	86,758	0.0265	3,551	0.710
1965	89,393	0.0268	4,027	0.731
1966	92,435	0.0261	4,932	0.752
1967	96,495	0.0266	6,120	0.785
1968	101,618	0.0264	7,140	0.805
1969	107,693	0.0261	8,294	0.860
1970	114,398	0.0260	10,145	0.928
1971	122,211	0.0257	11,894	1.000
1972	130,813	0.0254	13,385	1.057
1973	139,994	0.0256	14,907	1.124
1974	149,499	0.0254	16,350	1.355
1975	157,620	0.0258	15,090	1.584
1976	162,950	0.0262	16,979	1.676
1977	168,674	0.0262	19,758	1.801
1978	175,087			

Note: Value of capital stock is as of January 1.

The capital stock series (as of January 1) in 1971 dollars was then computed using the following formula:

$$K_{t+1} = I_t + (1-\delta)K_t - \delta(I_t/2). \tag{46}$$

EEI's data on construction expenditures in investor-owned electric utilities offered a suitable proxy for gross investment in current prices. Division by the adjusted Handy-Whitman index served to reduce these figures to constant (1971) dollars. The last term in equation (46) implicitly assumes that new plant and equipment are placed in service on July 1. The capital stock series so obtained is given in Table 4.

Output, Q, was measured as electricity generated by investor-owned utilities (in billions of kilowatt-hours). Thus, calculation of average revenue per kilowatt-hour (kWh) sold seemed the logical method for obtaining the price of output, P. Both series are listed in Table 5.

A weighted average of the after-tax cost of debt, preferred stock and common equity furnished an operational definition of the cost of financial capital, r:

$$r = \sum_{i=1}^{3} w_i r_i, \tag{47}$$

where r_i is the after-tax rate of return on bonds, preferred stock, and common stock respectively and w_i is the appropriate capitalization ratio for each financial instrument. The rate of return on bonds, r_1, is the market yield on newly issued power, light, and gas bonds. Since interest payments are a deductible expense for tax purposes, r_1 must be adjusted to reflect the after-tax cost of debt. The appropriate adjustment factor is (1-u), where u is the marginal rate of taxation and represents the value in

TABLE 5

INVESTOR-OWNED ELECTRIC UTILITIES:
OUTPUT AND PRICE OF OUTPUT

Year	Output kWh (Billions)	Price of Output (¢/kWh)
1954	371	1.88
1955	421	1.80
1956	459	1.78
1957	481	1.80
1958	490	1.85
1959	544	1.82
1960	580	1.82
1961	607	1.82
1962	653	1.80
1963	701	1.77
1964	756	1.73
1965	809	1.70
1966	881	1.67
1967	928	1.66
1968	1019	1.64
1969	1102	1.63
1970	1183	1.68
1971	1250	1.78
1972	1357	1.86
1973	1449	1.97
1974	1441	2.50
1975	1487	2.94
1976	1582	3.11
1977	1684	3.44

Note: Price of output is in current dollars.

effect for most of each year during the period 1954-1977. The rate of return on preferred stock, r_2, is the average dividend rate, and that on common stock, r_3, the reciprocal of the price/earnings ratio of public utility common stocks [11]. The marginal tax rates and weighted costs of capital are presented in Table 6.

Computation of the present value of the depreciation deduction, z, employed the double-declining-balance method (see Table 3) and a lifetime of 28 years. This is the figure given by the Internal Revenue Service as the serviceable life of electric utility steam production plant [12]. The user cost of capital, RA_t, was then calculated using equation (37) for years prior to 1964 and equation (38) for the period 1964-1977. The investment tax credit (ITC) rate, k, is that which was applicable to electric utilities in any given year. Annual rates reflect the following:

(1) suspension of the ITC on October 10, 1966;

(2) reinstatement of the ITC on March 10, 1967;

(3) repeal of the ITC on March 19, 1969;

(4) reinstatement of the ITC on January 22, 1971; and

(5) revision of the ITC rate on January 22, 1975 [13].

The Revenue Act of 1962 allowed an ITC only on utilities' equipment. Structures were excluded. Since structures and equipment are not separated in the available investment data, an effective ITC rate was calculated. The ratio of change in equipment to change in total steam production plant produced a suitable adjustment factor [14]. Although the ratio remained fairly stable over the period, three different figures were applied. For the years 1962-1970, the 1962 ratio of 85.7 percent

TABLE 6

INVESTOR-OWNED ELECTRIC UTILITIES:
WEIGHTED COST OF CAPITAL, MARGINAL FEDERAL INCOME TAX (FIT) RATE, APPLICABLE INVESTMENT TAX CREDIT (ITC) RATE, AND USER COST OF CAPITAL

Year	Weighted Cost of Capital (%)	Marginal FIT Rate	Effective ITC Rate (%)	User Cost of Capital
1954	3.74	0.520	-	0.0467
1955	3.77	0.520	-	0.0488
1956	3.98	0.520	-	0.0559
1957	4.31	0.520	-	0.0633
1958	3.86	0.520	-	0.0593
1959	3.88	0.520	-	0.0603
1960	3.90	0.520	-	0.0607
1961	3.46	0.520	-	0.0543
1962	3.52	0.520	2.57	0.0546
1963	3.38	0.520	2.57	0.0534
1964	3.54	0.500	2.57	0.0550
1965	3.64	0.480	2.57	0.0571
1966	4.36	0.480	1.97	0.0675
1967	4.67	0.480	2.09	0.0749
1968	4.80	0.528	0.76	0.0841
1969	5.33	0.528	-	0.0991
1970	6.26	0.492	-	0.1179
1971	5.89	0.480	3.25	0.1129
1972	6.26	0.480	3.45	0.1252
1973	6.81	0.480	3.45	0.1439
1974	9.32	0.480	3.29	0.2322
1975	9.24	0.480	7.94	0.2527
1976	8.33	0.480	8.23	0.2418
1977	7.95	0.480	8.23	0.2484

was employed. Reinstatement of the ITC in 1971 at a higher rate seemed significant; so, the 1971 ratio of 86.3 percent was used through 1973. The years 1974-1977 were adjusted by the 1974 ratio of 82.3 percent [15].

Notes

[1] See Lau [1969].

[2] See Joskow [1974]. Professor Joskow was most helpful in providing his work papers and source data. His assistance is greatly appreciated.

[3] The percent of firms filing rate-of-return reviews in any given year was calculated using data from Ebasco Business Consulting Company [1950-1978]. These figures may be found in Table 7. A variety of alternative proxies for the intensity of regulatory pressure have been suggested. They include the cost of capital, a weighted percent of firms filing rate-of-return reviews (the weighting factor being revenues, number of customers, or gross utility plant), and the actual number of rate-of-return reviews filed. The task of examining these alternatives is left to another study.

[4] $$r_t = \sum_{i=1}^{3} w_{it} r_{it},$$

where r_{it} is the after-tax rate of return on common stock, preferred stock, and bonds respectively and w_{it} is the appropriate relative weight of each financial instrument in the total capital structure in period t.

[5] For an explicit derivation of equation (37), see either Hall and Jorgenson [1967] or Coen [1968].

[6] See, for example, U.S. Federal Energy Regulatory Commission [1979, p. 31].

[7] Following Hall and Jorgenson [1967] and Rennie [1977], it is assumed throughout this analysis that the asset has no salvage value.

[8] See Edison Electric Institute [1970, 1957, 1958, 1959, and 1978], U.S. Department of Energy [1978], U.S. Federal Power Commission [1954-1977], and Moody's Investor Service, Inc. [1978], respectively.

[9] The Handy-Whitman index is constructed on a geographical basis for capital expenditures and is structured with 1949 = 1.0. The index used in this study is a composite of over 50 materials and labor items included in the Handy-Whitman Index Service of cost indexes of construction and equipment: all steam. This index has been restructured such that 1971 = 1.0. See Whitman, Requardt and Associates [1979].

[10] This methodology is employed by the FPC. See U.S. Federal Power Commission, Office of Economics [1975].

[11] All three measures are as per Moody's Investor Service, Inc. [1978].

[12] See U.S. Department of the Treasury [1978, p. 36].

[13] For example, the actual ITC rate in 1966 was 3.0 percent. However, suspension of the ITC on October 10 of that year made the annual rate 2.3 percent. Since the 3.0 percent credit was in effect only 282 days out of 365, the annual effective rate was 77.3 percent (= 282 ÷ 365) of 3.0 percent or 2.3 percent.

[14] See Bischoff [1971] and Rennie [1977].

[15] This is the methodology employed by Rennie [1977]. However, he used the 1962 figure throughout his study.

CHAPTER VI

EMPIRICAL RESULTS

Estimation of the Investment Function

$\hat{R}_t$, a proxy for the user cost of capital adjusted for the effects rate-of-return regulation, was estimated using the same procedure employed by Ando, Modigliani, Rasche, and Turnovsky [1974]. In equation (36), RA_t represents the user cost of capital in the absence of regulation. Its formulation, equations (37) and (38), accounts for all pertinent financial variables including taxes, the discount rate, the rate of replacement, investment credits and depreciation deductions. Thus, one may infer that the effects of regulation on the user cost of capital will be reflected in the difference between RA_t and $\hat{R}_t$; and it is the latter which is relevant in determining the coefficients of the investment function for regulated electric utilities, i.e., equation (35). Since α, the measure of regulatory effectiveness, is an unknown parameter in equation (36), equations (35) and (36) must be estimated simultaneously [1].

It is assumed that the percent of firms filing rate-of-return reviews, π_t, may be used as a proxy for the effectiveness of the regulatory constraint. This assumption is consistent with the findings of Joskow [1974]. Table 7 presents the percent of firms filing rate-of-return reviews over the study period [2]. The results are comparable to

TABLE 7

INVESTOR-OWNED ELECTRIC UTILITIES:
PERCENT OF FIRMS FILING RATE-OF-RETURN REVIEWS

Year	Percent of Firms Filing Reviews
1954	13.8
1955	5.1
1956	9.6
1957	17.3
1958	22.4
1959	15.7
1960	10.4
1961	7.4
1962	7.1
1963	2.6
1964	0.4
1965	1.6
1966	1.2
1967	3.5
1968	15.7
1969	28.1
1970	35.3
1971	58.3
1972	46.5
1973	48.9
1974	58.6
1975	52.9
1976	56.5
1977	49.4

Source: Ebasco Business Consulting Company [1950-1978].

Joskow's periods of regulatory activity. He found the years 1961-1968 to be years of little formal regulatory review because earned rates in the industry were generally greater than permitted rates. Table 7 reflects this fact since π_t varies considerably over the study period. Thus, rate-of-return regulation has ample opportunity to influence both the timing and degree of fluctuations in RA_t.

As an exemplary case, Figure 1 demonstrates that rate-of-return regulation can noticeably affect the user cost of capital over time. If $\alpha = 0$, then $\hat{R}_t = RA_t$ in every year. However, for α equal to say, 0.125, $\hat{R}_t$ varies from .0552 in 1955 to .3188 in 1975; and the time path of $\hat{R}_t$ differs markedly from that of RA_t.

Various series of $\hat{R}_t$ were generated using equation (36) and varying α from 0 to 1.0 at intervals of 0.001. The different series of $\hat{R}_t$ were then used in the investment function, equation (35), as a proxy for c_{rt}, the user cost of capital including the effects of regulation. The value of α yielding the best fit for equation (35) was assumed to be indicative of the effect of rate-of-return regulation on the user cost of capital.

Equation (35) allows for numerous formulations and lag structures. The polynomial lag specifications were constrained to maximums of $m = 8$ and $n = 2$. All possible formulations were estimated for α, RA_t, and the resulting $\hat{R}_t$. In every case, $\alpha = 0$ provided the best explanatory power. Hence, an initial and premature conclusion was drawn that rate-of-return regulation was not significant in determining the user cost of capital relevant for investment decisions in privately owned electric utilities.

Examination of the standard errors of the regression equations revealed that they rose monotonically as α increased. The question then arose as to whether α might not be negative. The theoretical implication

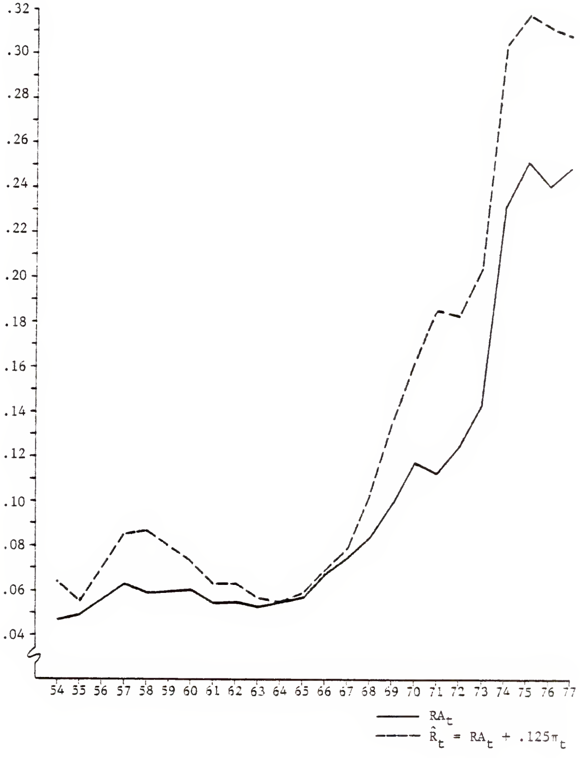


FIGURE 1

POSSIBLE EFFECTS OF RATE-OF-RETURN REGULATION
ON THE USER COST OF CAPITAL:
AN EXEMPLARY CASE

of this hypothesis is that rate-of-return regulation could conceivably reduce the user cost of capital.

In their seminal article, Averch and Johnson [1962] concluded that rate-of-return regulation would cause a profit-maximizing firm to over-capitalize and expand output beyond that which it would produce in the absence of regulation.

If Figure 2 denotes production where capital, K, is plotted on the vertical axis and all other factor inputs, X, on the horizontal axis, the market or social costs of capital and all other inputs generate the iso-cost curve I. In the absence of regulation, profit maximization would cause production to vary along expansion path A, where costs are minimized for any given output. With regulation, however, the cost of capital is effectively reduced. On each additional unit of capital input, a profit is permitted by the regulating authority. This profit equals the difference between the cost of capital, r in equation (4), and the rate of return, s in equation (4), allowed by the regulating agency. This is profit that would otherwise be foregone. Therefore, the cost of capital falls relative to that of other inputs. "The effect of regulation is analogous to that of changing the relative prices of capital [K] and [all other inputs X]" [Averch and Johnson 1962, p. 1053]. Isocost curve II becomes relevant and production fluctuates along expansion path B where social costs are not minimized for any given output. Path B is found to be advantageous simply because it is the one which offers profit maximization subject to the constraint, equation (4), on rate-of-return. A mathematical treatment of the so-called Averch-Johnson (A-J) effect is considered in Appendix C [3].

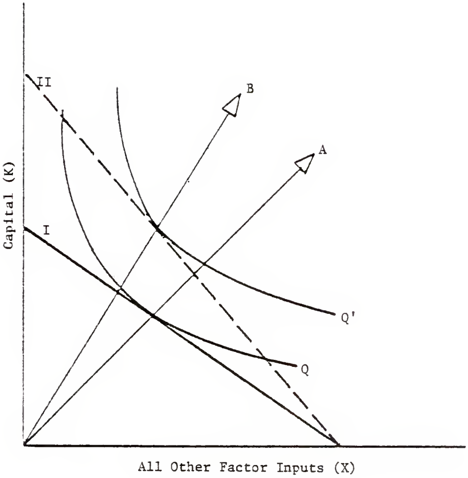


FIGURE 2

DIAGRAMMATIC REPRESENTATION OF
THE AVERCH-JOHNSON EFFECT
ACCOMPANIED BY OUTPUT EXPANSION

Electric utilities operate in a limited service area and are required to meet demand within that area. It can be argued that imposing rate-of-return regulation will not induce an expansion of output similar to that depicted in Figure 2. That is, if isoquant Q represents a level of output sufficient to meet demand, then there will be no incentive to expand production to Q' in the presence of rate-of-return regulation.

At the firm level, this contention is not quite correct. Although a utility does have a restricted territory in which it may operate as a monopoly, it is not prohibited from selling excess output to other utilities for resale. In other words, a very real opportunity exists for an individual firm to expand its production and market it profitably. Thus, rate-of-return regulation, under the assumptions of the A-J hypothesis, may result in increased production as well as overcapitalization at the firm level.

For the industry as a whole, the possibility of increased output offers far less appeal. Assuming aggregate demand is being met before rate-of-return regulation is introduced, the conclusion that output will increase in its wake has little justification. The industry has no lucrative outlet for incremental output. Presumably, customers were receiving the amounts desired before regulation was imposed. Thus, at least at the industry level, one may assume that rate-of-return regulation will not have an appreciable effect on the level of production.

However, absence of the output expansion effect does not preclude the possibility of overcapitalization. Figure 3 is analogous to Figure 2 except that output remains constant at level Q both before and after the advent of regulation. The market costs of the inputs generate isocost curve I. Unregulated profit maximization predicts that production will occur at point a. Since expansion path A represents the cost-minimizing

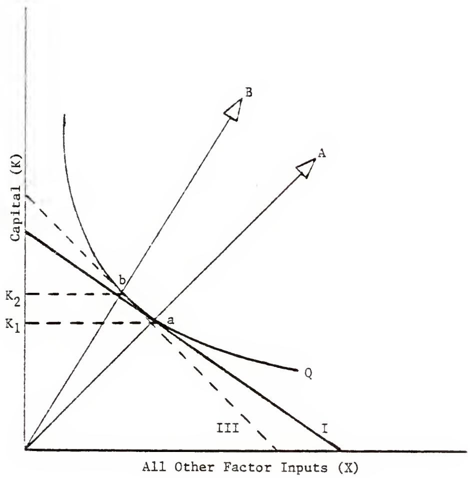


FIGURE 3

DIAGRAMMATIC REPRESENTATION OF
THE AVERCH-JOHNSON EFFECT
IN THE ABSENCE OF OUTPUT EXPANSION

positions for every level of output, point a denotes the combination of capital and all other inputs which will minimize the cost of producing Q.

With rate-of-return regulation, the profit permitted on each unit of capital may effectively reduce the cost of capital relative to that of other inputs. The new relative prices would make isocost curve III appropriate. Even if the level of output remained unchanged, the profit-maximizing combination of inputs would be altered. The amount of capital employed in producing Q could be expected to rise from a level such as K_1 to a level such as K_2. Regulation would induce an increase in the capital stock and, thus, affect investment.

Within the A-J framework, rate-of-return regulation theoretically reduces the cost of capital relative to the cost of other inputs. Thus, it was decided α, in equation (36), should be allowed to assume negative values. The procedure utilized essentially the same technique as that employed for $\alpha > o$.

New series of $\hat{R}_t$ were generated using equation (36) and changing α from 0 in decrements of 0.001. Varying from 0 to 1.0 implicitly assumed that regulation could have anywhere from an insignificant impact on RA_t ($\alpha = 0$) to one reflecting the full measure of regulatory pressure ($\alpha = 1$). However, as Table 8 reveals, permitting to take on values less than -.200 leads to a negative user cost of capital in some years. Since such a result is nonsensical and in contradiction with the basic tenets of price theory, the following constraint was imposed:

$$\text{(48)} \qquad \alpha \geq -\frac{RA_t}{\pi_t} \quad \forall \quad t,$$

which restricts to values greater than -.194.

TABLE 8

VALUES OF $\hat{R}_t$ ASSOCIATED WITH VARIOUS VALUES OF α

	VALUES OF $\hat{R}_t$			
Year	α = -.015	α = -.200	α = -.201	α = -.300
1954	.0446	.0191	.0190	.0053
1955	.0480	.0386	.0385	.0335
1956	.0545	.0397	.0396	.0301
1957	.0607	.0287	.0285	.0114
1958	.0559	.0145	.0143	-.0079
1959	.0579	.0289	.0287	.0132
1960	.0591	.0399	.0398	.0295
1961	.0532	.0395	.0394	.0321
1962	.0535	.0404	.0403	.0333
1963	.0530	.0482	.0482	.0456
1964	.0544	.0542	.0542	.0538
1965	.0569	.0539	.0539	.0523
1966	.0673	.0651	.0651	.0639
1967	.0744	.0679	.0679	.0644
1968	.0817	.0527	.0525	.0370
1969	.0949	.0429	.0426	.0148
1970	.1126	.0473	.0469	.0120
1971	.1042	-.0037	-.0043	-.0620
1972	.1182	.0322	.0317	-.0143
1973	.1366	.0461	.0456	-.0028
1974	.2234	.1150	.1144	.0564
1975	.2448	.1469	.1464	.0940
1976	.2333	.1288	.1282	.0723
1977	.2410	.1496	.1491	.1002

The order of the $\gamma(L)$ polynomial in equation (35) was restricted to eight and the order of the $\omega(L)$ polynomial to two [4]. These restrictions permitted a maximum of eight lagged changes in the relative price variable, eight lagged changes in the output variable, and two lagged changes in the dependent variable. All possible specifications were re-estimated under OLS procedures for each new α, RA_t, and resulting $\hat{R}_t$. The technique employed in selecting the final regression was essentially the same as that used by Sankar [1972]. The equation chosen was the one which minimized the standard error of the regression, s, subject to the condition that the leading coefficients of the $\gamma(L)$ polynomial be non-negative. Noting that $\alpha = -.015$ consistently provided the best explanatory power, the final equation was:

$$\begin{aligned} \Delta \ell n K_t = {} & \underset{(.016)}{.0339} \ \Delta \ell n \left(\frac{P}{c}\right)_{t-6} + \underset{(.060)}{.0831} \ \Delta \ell n \, Q_{t-6} + \underset{(.020)}{.0758} \\ & \Delta \ell n \left(\frac{P}{c}\right)_{t-8} + \underset{(.052)}{.1336} \ \Delta \ell n \, Q_{t-8} + \underset{(.095)}{.8221} \ \Delta \ell n \, K_{t-1} + \nu_t \ , \end{aligned} \tag{49}$$

$s = .0051 \qquad R^2 = .9179 \qquad \bar{R}^2 = .8851 \qquad d = 2.1174.$

Standard errors are reported in parentheses.

The results are presented in detail in Figure 4 which replicates the printout obtained from the Econometrics Software Package (ESP) [5], and where the variables are defined as follows:

CLDK8 $= \Delta \ \ell n \ K_t$,

CDP6 $= \Delta \ \ell n \ (P/c)_{t-6}$,

CLQ6 $= \Delta \ \ell n \ Q_{t-6}$,

CLP8 $= \Delta \ \ell n \ (P/c)_{t-8}$,

CLQ8 $= \Delta \ \ell n \ Q_{t-8}$, and

CLDK81 $= \Delta \ \ell n \ K_{t-1}$.

ORDINARY LEAST SQUARES

VARIABLES...

CLDK8
CLP6
CLQ6
CLP8
CLQ8
CLDK81

INDEPENDENT VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
CLP6	0.339289E-01	0.158459E-01	2.14064
CLQ6	0.831034E-01	0.602254E-01	1.37987
CLP8	0.757649E-01	0.204816E-01	3.69917
CLQ8	0.133591	0.515707E-01	2.59045
CLDK81	0.822097	0.946344E-01	8.68703

R-SQUARED = 0.9179

F-STATISTIC(4, 10) = 27.9411

DURBIN-WATSON STATISTIC (ADJ. FOR 0 GAPS) = 2.1174

NUMBER OF OBSERVATIONS = 15

SUM OF SQUARED RESIDUALS = 0.257577E-03

STANDARD ERROR OF THE REGRESSION = 0.507521E-02

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

0.251E-03	0.244E-03	-0.471E-04	-0.237E-03	0.219E-03
0.244E-03	0.363E-02	0.152E-03	-0.290E-03	-0.392E-02
-0.471E-04	0.152E-03	0.419E-03	0.695E-03	-0.753E-03
-0.237E-03	-0.290E-03	0.695E-03	0.266E-02	-0.274E-02
0.219E-03	-0.392E-02	-0.753E-03	-0.274E-02	0.896E-02

FIGURE 4

DETAILED REGRESSION RESULTS FOR
THE INVESTMENT FUNCTION, EQUATION (49)

It should be noted that the computer regression routine employs the formula:

$$(50) \qquad R^2 = 1 - (RSS/S_{yy})$$

where RSS = the residual sum of squares,

$S_{yy} = \Sigma\, y_i^{\,2} - n\bar{y}^2,$

y = the dependent variable,

n = the number of observations, and

$\bar{y}$ = the sample mean of y.

This formula for R^2 is used by the package for equations with and without constant terms.

Maddala [1977] has pointed out that in the absence of a constant term, there will be no "mean corrections" [6]. For example, $S_{yy} = \Sigma\, y_i^{\,2}$ and not $\Sigma\, y_i^{\,2} - n\bar{y}^2$. Although ESP allows the option of excluding the constant term, it does not give the correct R^2 in such a case.

However, an intercept term may be added to equation (49) and interpreted as the sample mean of the error in the equation [7]. The corresponding regression function including an intercept is:

$$(51) \qquad \Delta \ell n K_t = \underset{(.010)}{-\ .0059} + \underset{(.019)}{.0395}\ \Delta \ell n \left(\frac{P}{c}\right)_{t-6} + \underset{(.097)}{.1251}\ \Delta \ell n\ Q_{t-6}$$

$$+ \underset{(.022)}{.0799}\ \Delta \ell n \left(\frac{P}{c}\right)_{t-8} + \underset{(.081)}{.1676}\ \Delta \ell n\ Q_{t-8}$$

$$+ \underset{(.014)}{.8423}\ \Delta \ell n\ K_{t-1} + \nu_t,$$

$s = .0053 \qquad R^2 = .9207 \qquad \bar{R}^2 = .8766 \qquad d = 2.1034$

Standard errors are reported in parenthesis.

A comparison of the two equations shows them to be strikingly similar. Thus, although the R^2 reported for equation (49) is not exact, the results of (51) lend support to the contention that it is probably a

close approximation. This contention is further borne out in succeeding sections. A graph of the actual and estimated net investment, Figure 5, is especially convincing.

Since Sankar's formulation is similar to the model used in this study, an investigation of his results was conducted to determine whether or not the statistics he reported reflect the appropriate R^2. Using the data published in Sankar [1972, p. 653] and his chosen lag structure, his final equation was reestimated with ESP and the results are as follows:

$$(52)\ \Delta\ell n\ K_t = \underset{(.045)}{.0482}\ \Delta\ell n\ \left(\frac{P}{c}\right)_{t-2} + \underset{(.048)}{.1850}\ \Delta\ell n\ Q_{t-2}$$

$$+ \underset{(.0215)}{.9930}\ \Delta\ell n\ K_{t-1} - \underset{(.178)}{.2898}\ \Delta\ell n\ K_{t-2} + \nu_t,$$

$$s = .0071 \qquad R^2 = .8606 \qquad \bar{R}^2 = .8345 \qquad d = 1.5417$$

Standard errors are reported in parentheses.

Equation (52) is a veritable reproduction of Sankar's equation with only minor differences in some of the final decimal places. Thus, it seems clear that Sankar's statistical routine calculated the value of R^2 in the same manner as ESP. However, Sankar's failure to acknowledge this flaw serves to mislead the reader somewhat.

Equation (49) is the final specification of the investment function employed for the remainder of this study [8]. Overall, the equation seems acceptable. The t ratios of the estimated coefficients are all significant at the .10 level, all but two are significant at the .05 level and the F statistic is highly significant at the .01 level.

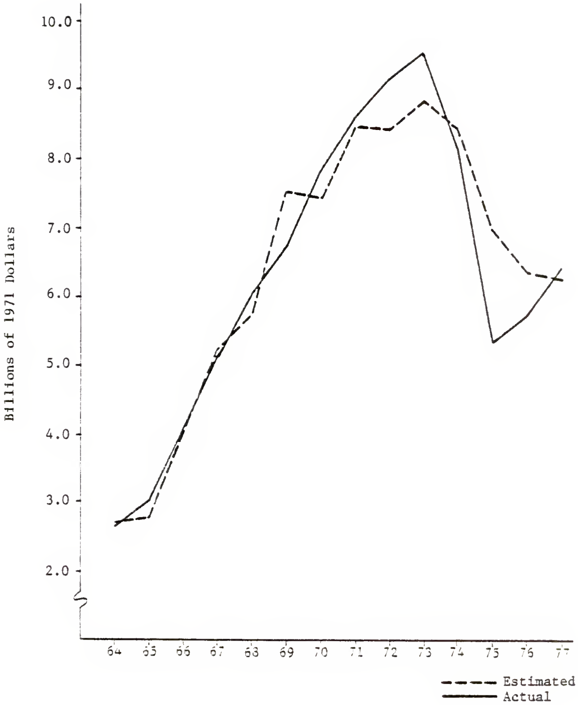


FIGURE 5

ACTUAL AND ESTIMATED NET INVESTMENT, 1964-1977

The estimated coefficients from equation (49) imply the following approximations of the long-run elasticities of capital stock with respect to relative price and output:

$$\hat{E}_{(\frac{P}{c})} = \hat{\sigma} = \frac{\hat{\gamma}_{P6} + \hat{\gamma}_{P8}}{1 + \hat{\omega}_1} = .61664, \text{ and}$$

$$\hat{E}_{(Q)} = \widehat{\left\{ \sigma + \frac{1 - \sigma}{k} \right\}} = \frac{\hat{\gamma}_{Q6} + \hat{\gamma}_{Q8}}{1 + \hat{\omega}_1} = 1.21810,$$

where output represents kWh generated to serve consumers (or an approximation of quantity demanded). The implied point estimate of the returns-to-scale parameter, k, is 0.63738.

The elasticity estimates are both larger than Sankar's. This indicates that investment has become more responsive to changes both in relative price and output. The long-run elasticity of capital stock with respect to output indicates that the industry is altering investment in a proportion greater than its percentage change in output. This makes sense since larger generating units require greater reserve capacity and the trend has been to larger facilities over the study period. Additionally, firms have been required to invest in pollution control equipment in conjunction with environmental legislation. This would tend to increase investment (measured as a flow of funds) in a greater proportion than perhaps demand would warrant. It should be noted that investment is nearly twice as responsive to changes in output as to changes in relative price. This is consistent with the widely held view that because of long-term planning considerations and large capital outlays, investment decisions by electric utilities are predicated mostly on demand.

The implied point estimate of the returns-to-scale parameter is substantially lower than Sankar's. Since this study covers a more recent time period, this result lends support to the contention that many electric utilities may have exhausted some economies of scale. This point is considered further in a following section.

Examination of the Possibility of Serial Correlation

Serial correlation problems are especially serious in distributed lag models estimated in the autoregressive form. Griliches [1961] discusses the serial correlation biases in the estimates of the coefficients of a distributed lag model. He shows that under OLS procedures the estimated ρ will be biased toward zero. Thus, it is more likely that the null hypothesis of $\rho = 0$ will be accepted even when $\rho \neq 0$. Since investment data are likely to exhibit a high degree of autocorrelation, a method is needed to test for this possibility.

The most commonly used test is the Durbin-Watson test [9]. It is defined as:

$$d = \frac{\sum_{t=2}^{n} (\hat{e}_t - \hat{e}_{t-1})^2}{\sum_{t=1}^{n} \hat{e}_t^2} ,$$

where $\hat{e}_t$ is the estimated residual from the least-squares regression. The Durbin-Watson statistics, d, are reported for all equations estimated in this study, but the manner in which the test is derived makes it inappicable to cases where a lagged dependent variable occurs on the right-hand side of the equation [10]. Since the final investment function,

equation (35), does involve a lagged dependent regressor, the Durbin-Watson test statistic cannot be used.

It should be noted that the hazard here lies in accepting the null hypothesis of $\rho = 0$ even when $\rho \neq 0$. Thus, if the Durbin-Watson test rejects the null hypothesis it can be used. The Durbin-Watson statistic from equation (49) is 2.1174. At a 5.0 percent level of significance, it lies between the upper and lower limits calculated by Durbin and Watson [1950] for a sample with fifteen observations and five explanatory variables. The test is inconclusive; the null hypothesis of no autoregression ($\rho = 0$) cannot be rejected; and the Durbin-Watson test is not valid. However, the serial correlation problem cannot be ignored since its presence will lead to inconsistent estimates of the parameters.

Durbin [1970] has suggested an alternative test that can be used when a function involves a lagged dependent variable. The statistic is defined as:

$$h = \hat{\rho} \sqrt{\frac{N}{1 - N \hat{V}(\hat{\omega}_1)}}$$

where: $\hat{\rho}$ = the estimated serial correlation computed from the OLS residuals,

N = the number of observations,

$\hat{\omega}_1$ = the OLS estimate of the parameter for the lagged dependent regressor, and

$\hat{V}(\hat{\omega}_1)$ = the estimated variance of $\hat{\omega}_1$.

Since h has a normal distribution, it may be used as a standard normal deviate for testing the hypothesis $\rho = 0$. However, the test is

appropriate only for large samples, i.e., $N \geq 30$. The parameters in equation (49) were estimated using annual data for a fifteen-year period. Thus, the sample size is not sufficient to permit the use of Durbin's h statistic as a test for serial correlation.

The residuals from equation (49) are plotted in Figure 6. The contingency table shown below facilitates examination of the sign pattern of these residuals:

	Positive at t	Negative at t
Positive at t-1:	5	3
Negative at t-1:	4	2

In the case of randomness ($\rho=0$), one expects the entries to be evenly distributed in the four cells. It can be seen that there is no evidence of either positive or negative serial correlation in the residuals. Examination of the plotted residual values in Figure 6 leads to a similar conclusion as they seem to be randomly dispersed throughout the study period. Thus, a preliminary analysis of the residuals revealed that the existence of serial correlation in equation (49) was minimal at best.

The residuals were then regressed on their lagged values. A first-order autoregressive scheme of the form:

$$\hat{e}_t = \rho \, \hat{e}_{t-1} + \nu_t \, ,$$

was assumed. This implied that the disturbance in period t equals a portion (ρ) of the disturbance in period t-1 plus a random effect represented by ν_t. The results are as follows:

$$\hat{e}_t = \underset{(.273)}{-.0761} \, \hat{e}_{t-1} + \nu_t \, , \tag{53}$$

$$s = .0044 \qquad R^2 = .0055 \qquad \bar{R}^2 = .0055 \qquad d = 2.0415.$$

PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(*)

ID	ACTUAL	FITTED	RESIDUAL
1963	0.2949E-01	0.3223E-01	-0.274E-02
1964	0.2992E-01	0.3068E-01	-0.765E-03
1965	0.3346E-01	0.3039E-01	0.307E-02
1966	0.4299E-01	0.4285E-01	0.135E-03
1967	0.5173E-01	0.5277E-01	-0.105E-02
1968	0.5806E-01	0.5503E-01	0.303E-02
1969	0.6040E-01	0.6753E-01	-0.713E-02
1970	0.6607E-01	0.6241E-01	0.366E-02
1971	0.6802E-01	0.6707E-01	0.946E-03
1972	0.6783E-01	0.6234E-01	0.549E-02
1973	0.6569E-01	0.6165E-01	0.404E-02
1974	0.5290E-01	0.5543E-01	-0.253E-02
1975	0.3326E-01	0.4364E-01	-0.104E-01
1976	0.3452E-01	0.3286E-01	0.167E-02
1977	0.3732E-01	0.3625E-01	0.106E-02

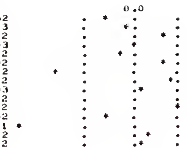


FIGURE 6

ACTUAL AND FITTED VALUES OF $\Delta \ell n K_t$ AND
RESULTING RESIDUALS FROM EQUATION (49)

Recalling that ESP does not give quite accurate statistics in the absence of a constant term, equation (53) was reestimated with a constant term for comparison purposes. The resulting regression is:

(54) $$\hat{e}_t = \underset{(.001)}{.00007} - \underset{(.284)}{.0753}\, \hat{e}_{t-1} + \nu_t,$$

$$s = .0046 \quad R^2 = .0058 \quad \bar{R}^2 = -.0771 \quad d = 2.0434.$$

Thus, an extensive analysis of the residuals from equation (49) indicated that autocorrelation was not a problem in the regression.

Finally, the Cochrane-Orcutt iterative procedure was run to check for the presence of serial correlation [Cochrane and Orcutt 1949]. The value of ρ converged to .0513 after six iterations, and the final equation was:

(55) $$\begin{aligned} \Delta\ell n\, K_t = {} & \underset{(.019)}{.0244}\, \Delta\ell n\, \left(\frac{P}{c}\right)_{t-6} + \underset{(.062)}{.0793}\, \Delta\ell n Q_{t-6} \\ & + \underset{(.023)}{.0832}\, \Delta\ell n\, \left(\frac{P}{c}\right)_{t-8} + \underset{(.080)}{.1896}\, \Delta\ell n\, Q_{t-8} \\ & + \underset{(.117)}{.7547}\, \Delta\ell n\, K_{t-1} + \nu_t \end{aligned}$$

$$s = .0051 \quad R^2 = .9134 \quad \bar{R}^2 = .8749 \quad d = 2.0307.$$

Inclusion of a constant term produced an autocorrelation parameter of $-.0129$ after two iterations. The resulting equation was:

(56) $$\begin{aligned} \Delta\ell n\, K_t = {} & \underset{(.011)}{-.0057} + \underset{(.022)}{.0308}\, \Delta\ell n\, \left(\frac{P}{c}\right)_{t-6} + \underset{(.010)}{.1181}\, \Delta\ell n\, Q_{t-6} \\ & + \underset{(.025)}{.0882}\, \Delta\ell n\, \left(\frac{P}{c}\right)_{t-8} + \underset{(.104)}{.2190}\, \Delta\ell n\, Q_{t-8} \\ & + \underset{(.127)}{.7852}\, \Delta\ell n\, K_{t-1} + \nu_t \end{aligned}$$

$$s = .0054 \quad R^2 = .9163 \quad \bar{R}^2 = .8640 \quad d = 1.9903,$$

where the original estimate of the constant term (= -.0058) has been divided by $(1-\hat{\rho})$ to adjust for the transformation inherent in the Cochrane-Orcutt technique.

In both equations (55) and (56), the standard errors reported in parentheses are as calculated by the computer package. It is recognized that these figures are not quite correct since they do not take into account the fact that ρ has been estimated. However, the final values of ρ do not indicate that serial correlation is present in either regression and suggest that OLS procedures might be preferable [11]. The conclusion drawn is that equation (49) presents results in the absence of serial correlation. Since neither equation (55) or (56) is used further in this study, no attempt was made to adjust the standard errors.

Lag Structure of the Estimated Investment Function

In equation (49), a change in desired capital stock has its first effects on the changes in actual capital stock, or investment, six periods later. This result seems reasonable in lieu of the fact that electric utilities' planning horizons have lengthened markedly during the study period. The advent of nuclear generating facilities, larger conventional units and stringent environmental controls have all contributed to a substantial increase in the lead times required for new utility plant.

The coefficients imply a suitable economic lag structure in that the first-order difference equation indicated by the parameters is not explosive but rather converges. The responses of net investment to changes in relative price and output are given in Table 9. It can be seen from

TABLE 9

DISTRIBUTED LAG COEFFICIENTS: RESPONSES OF INVESTMENT TO RELATIVE PRICE AND OUTPUT CHANGES

$$\Delta \ln K_t = .03373 \ \Delta \ln(P/c)_{t-6} + .08310 \ \Delta \ln Q_{t-6} + .07576 \ \Delta \ln(P/c)_{t-8} + .13359 \ \Delta \ln Q_{t-8} + .82210 \ \Delta \ln K_{t-1} + \nu_t$$

(1) i	(2) $\hat{\mu}_{Pi}$	(3) $\sum_{k=1}^{i} \hat{\mu}_{Pk}$	(4) $(3)/\hat{E}_{(\frac{P}{c})}$	(5) $\hat{\mu}_{Qi}$	(6) $\sum_{k=1}^{i} \hat{\mu}_{Qk}$	(7) $(6)/\hat{E}_{(Q)}$
0 to 5	0	0	0	0	0	0
6	.03393	.03393	.05502	.08310	.08310	.06822
7	.02789	.06182	.10025	.06832	.15142	.12431
8	.09870	.16052	.26031	.18976	.34118	.28009
9	.08114	.24166	.39190	.15600	.49718	.40816
10	.06670	.30836	.50006	.12825	.62543	.51345
11	.05484	.36320	.58900	.10543	.73086	.60000
12	.04508	.40828	.66210	.08667	.81753	.67115
13	.03706	.44534	.72220	.07125	.88878	.72964
14	.03047	.47581	.77162	.05858	.94736	.77774
15	.02505	.50086	.81224	.04816	.99552	.81727
16	.02059	.52145	.84563	.03959	1.03511	.84977
17	.01693	.53838	.87309	.03255	1.06766	.87650
18	.01392	.55230	.89566	.02676	1.09442	.89846
19	.01144	.56374	.91421	.02200	1.11642	.91653
20	.00941	.57315	.92947	.01808	1.13450	.93137
21 to ∞	.04349	.61664		.08360	1.21810	
SUM	.61664		1.00000	1.21810		1.00000

columns (2) and (5) that the relative weights are zero through period five, reach a maximum in period eight, and gradually decline thereafter.

The implied lag structure shows the proportion of net investment which results from a change in desired capital stock τ periods previous to the current period. To aid in visualizing the time pattern of response in net investment to a change in output, the elements of the $\mu(L)$ polynomial have been plotted in Figure 7. The first through fifth period responses are zero, the sixth period response is about .068, the seventh period response falls slightly, a maximum response is reached in period eight and declines thereafter.

Implications of the Estimated Value of α

Figure 8 depicts the time path of the user cost of capital with and without the effects of regulation. $\hat{R}_t$ represents the cost after rate-of-return regulation has been introduced. Since the final estimate of α is $-.015$, RA_t, the user cost of capital in the absence of regulation, is reduced somewhat when rate-of-return regulation is introduced. This result lends support to the Averch-Johnson (A-J) hypothesis in that a decrease in the cost of capital relative to that of other inputs suggests there may be overcapitalization in the industry. Firms may find it advantageous to substitute capital for other factor inputs in the presence of rate-of-return regulation.

Numerous examples of attempts to test the validity of the A-J hypothesis exist in the literature [12]. They cover various time periods and employ diverse methodologies [13]. Interestingly enough, the results of these studies are mixed. About half find evidence of the A-J effect

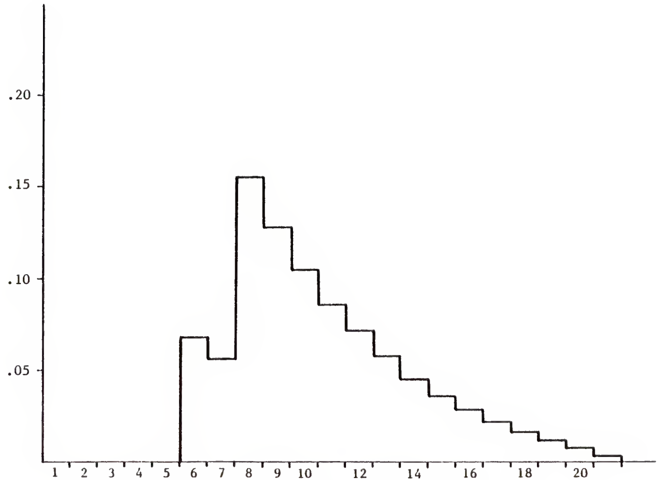


FIGURE 7

TIME FORM OF LAGGED RESPONSE
OF NET INVESTMENT TO CHANGES IN OUTPUT

while the remainder fail to find support for the A-J capital bias. Studies by Spann [1974], Courville [1974], Peterson [1975], and Hayashi and Trapani [1976] all lend credence to the A-J hypothesis.

It is noteworthy that of all the methodologies used to test this effect, none has employed an investment function. This is most surprising since the Averch-Johnson effect predicts an increase in the quantity of capital employed when rate-of-return regulation is imposed. It only seems reasonable that investment behavior should be considered when attempting to test a hypothesis which promulgates over-capitalization.

This study attempts to account for the effects of rate-of-return regulation on the investment behavior of regulated electric utilities. In so doing, it offers a new and novel approach to testing the Averch-Johnson effect. Estimation of the investment function simultaneously with the effective user cost of capital, R_t, reveals that investment behavior of privately owned electric utilities is best explained when the user cost of capital is reduced slightly.

The decrease in the user cost of capital in any period is influenced by the percent of firms filing rate-of-return reviews, π_t. As Figure 8 demonstrates, periods of minimal formal regulatory activity, e.g., 1961-1968, are periods where regulation plays a minor role in reducing the cost of capital. They are also years with relatively low capital costs.

This is consistent with the findings of Joskow [1974] who identifies the period 1961-1968 with decreasing costs which raised earned rates-of-return above allowed rates. Thus, fewer firms would be expected to file formal rate reviews and the period would be one characterized by little regulatory activity.

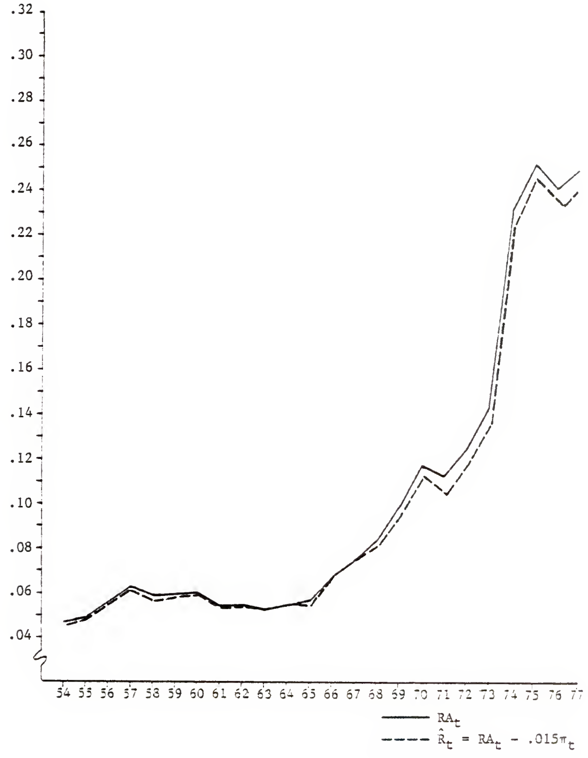


FIGURE 8

ESTIMATED EFFECTS OF RATE-OF-RETURN REGULATION
ON THE USER COST OF CAPITAL

During the years 1960-1965, inflation (as measured by changes in the wholesale price index) rose at a compound rate of about 0.4 percent per year while the user cost of capital, see Table 6, fell at a compound rate of about 5.9 percent per year. Even if prices in general had remained constant, the user cost of capital, RA_t, would have fallen relative to the price of other factors. Thus, electric companies would face an iso-cost curve similar to IV in Figure 9. Under such circumstances, rate-of-return regulation would reduce the user cost of capital from OS to OR. This is a smaller reduction than that which would have occurred had the cost of capital not fallen relative to the price of other inputs.

The period since 1970 has been one of intense regulatory activity. This was due to increasing costs which caused earned rates in the industry to fall below allowed rates. Inflation, as measured by the whole-sale price index, rose at a compound rate of about 8.4 percent per year between 1970 and 1977. The user cost of capital for electric utilities rose at a compound rate of about 11.2 percent per annum (see Table 6). Thus, the user cost of capital increased relative to the price of other inputs. An isocost curve similar to V in Figure 10, became relevant, and rate-of-return regulation could reduce the user cost of capital from OZ to OU, which is a larger reduction than that which would have occurred in the absence of the shift in relative prices.

In light of this framework, the time path of $\hat{R}_t$, the user cost of capital adjusted for the effects of regulation, seems reasonable. Firms will seek rate-of-return reviews when their earned rate drops below the allowed rate. This will happen when their costs rise. For the years being considered, two distinct periods are evident. The first is 1961-1965 which is characterized by earned rates in excess of allowed rates,

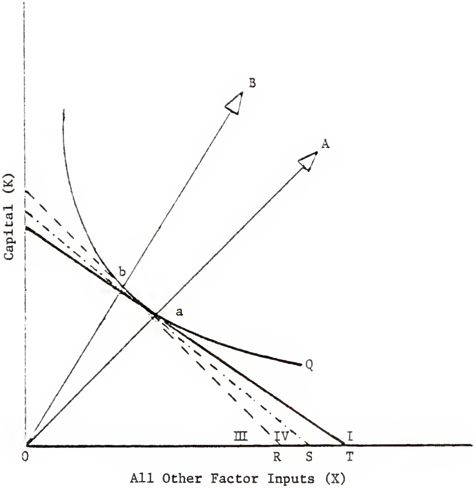


FIGURE 9

DIAGRAMMATIC REPRESENTATION OF
THE AVERCH-JOHNSON EFFECT
ACCOMPANIED BY A RELATIVE DECREASE IN
THE USER COST OF CAPITAL

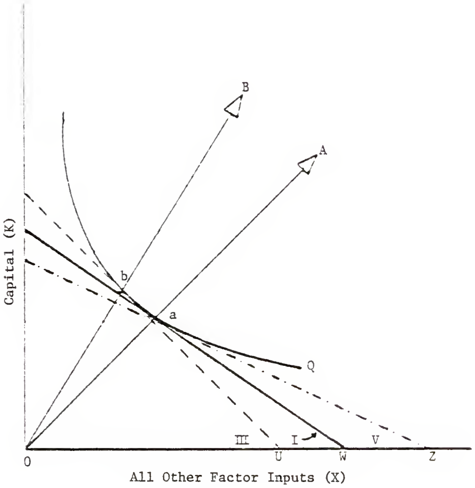


FIGURE 10

DIAGRAMMATIC REPRESENTATION OF
THE AVERCH-JOHNSON EFFECT
ACCOMPANIED BY A RELATIVE INCREASE
IN THE USER COST OF CAPITAL

little formal regulatory review, and decreasing capital costs relative to the prices of other inputs. During these years, regulation influences the user cost of capital less than in other years. The second period is 1970-1977 where regulatory activity was at its peak, earned rates were falling below allowed rates due to increasing costs, and the user cost of capital was rising relative to the cost of other factors.

Since the user cost of capital adjusted for the effects of regulation, $\hat{R}_t$, is consistently below the user cost in the absence of regulation, RA_t, there is some evidence that the A-J effect may, in fact, occur. This conclusion is a result of simultaneously estimating the investment function and the user cost of capital adjusted for rate-of-return regulation. It offers a fresh approach for testing the validity of the A-J hypothesis and incorporates the investment behavior of electric utilities which is central to the entire A-J analysis.

Modifications of the Investment Function

Examination of Figures 4 and 5 and the final investment function suggests that several modifications should be considered. First, the high significance level of the lagged dependent variable (Figure 4) relative to those of the other explanatory variables may imply that most of the explanatory power in the regression is due to the presence of this variable. Second, the fitted values of $\Delta \ell n K_t$ in equation (49) lead to some fluctuations in estimated net investment around actual net investment (see Figure 5) that may be due to a lagged response of industry investment to changes in the investment tax credit (ITC). Third, there is a possibility that economies of scale may have ceased to exist for

many electric utilities sometime around 1968. This may have had an effect on investment behavior. These possibilities were examined by adjusting the estimating program to reflect the formulation implied by each. The results of these analyses are reported below.

The regression $\Delta \ell n K_t = \beta \ \Delta \ell n K_{t-1}$ was run to determine how much the output and relative price variables contributed to equation (49). The Cochrane-Orcutt iterative technique was employed to purge the equation of serial correlation inherent in this formulation. The autocorrelation parameter converged to .4401 after one iteration and the final equation was:

(57) $$\Delta \ell n \ K_t = \underset{(.051)}{.9700} \ \Delta \ell n \ K_{t-1} + \nu_t$$

$$s = .0065 \qquad R^2 = .7767 \qquad \bar{R}^2 = .7767 \qquad d = 1.7518$$

The standard errors reported in parentheses have not been adjusted to reflect the estimation of ρ.

As expected, the coefficient of determination is markedly lower than the $\bar{R}^2$ for equation (49). The explanatory power of the model is substantially reduced when the desired capital stock variables are omitted. Although this model is rather naive, it does serve to support the inclusion of output and relative price in the final investment function.

In order to examine the possibility of a lagged industry response to changes in the ITC, the effective ITC rate (see Table 6) was lagged one period and used to reestimate equation (49). The resulting regression is:

(58) $$\begin{aligned} \Delta \ell n \ K_t = \ & \underset{(.018)}{.0386} \ \Delta \ell n \left(\frac{P}{c}\right)_{t-6} + \underset{(.065)}{.0899} \ \Delta \ell n \ Q_{t-6} \\ & + \underset{(.020)}{.0586} \ \Delta \ell n \left(\frac{P}{c}\right)_{t-8} + \underset{(.051)}{.1078} \ \Delta \ell n \ Q_{t-8} \\ & + \underset{(.102)}{.8361} \ \Delta \ell n \ K_{t-1} + \nu_t \end{aligned}$$

$$s = .0055 \qquad R^2 = .9049 \qquad \bar{R}^2 = .8669 \qquad d = 2.2059.$$

The explanatory power of the function fell slightly when a lagged ITC rate entered the model. The conclusion drawn is that utilities can sufficiently foresee tax changes and adjust their investment plans accordingly. This seems reasonable since alterations in tax policy generally involve rather lengthy legislative proceedings before enactment.

A final modification was considered in the estimation of equation (49). In order to investigate the possibility that economies of scale disappeared in much of the industry sometime during the study period (presumably around 1968) and, thus, affected investment behavior, a dummy variable was introduced. In order to save degrees of freedom the following methodology was employed. For years prior to 1968, the output variable, $\Delta \ell n Q_t$, was multiplied by 1. In later years, the multiplier used was 0. The resulting regression is:

$$(59) \quad \Delta \ell n\, K_t = \underset{(.019)}{.0355}\, \Delta \ell n \left(\frac{P}{c}\right)_{t-6} + \underset{(.056)}{.0671}\, \Delta \ell n\, Q_{t-6} + \underset{(.018)}{.0318}\, \Delta \ell n \left(\frac{P}{c}\right)_{t-8} + \underset{(.046)}{.1203}\, \Delta \ell n\, Q_{t-8} + \underset{(.044)}{1.04082}\, \Delta \ell n\, K_{t-1} + \nu_t$$

$$s = .0059 \qquad R^2 = .8886 \qquad \bar{R}^2 = .8440 \qquad d = 2.1310$$

Standard errors are reported in parentheses.

The explanatory power of the equation fell significantly. However, it should be noted that the first-order difference equation implied by the coefficients of equation (59) is explosive and, therefore, implies an unsuitable economic lag structure. Given this fact, it is not clear that any inference can be made from these results. It may well be that the dummy variable approach is not appropriate for examining the effect of

changes in economies of scale on investment decisions. Further investigation of the possibility of such an effect offers an interesting topic for future research, but is beyond the scope of this paper.

The conclusion of this analysis is that equation (49) offers a suitable formulation of the investment function of regulated electric utilities during the study period. Its explanatory power is not improved by any of the modifications suggested. Thus, it will be used as the final investment equation resulting from this study. A comparison of equation (49) and alternative investment specifications is conducted in Chapter VII.

Notes

[1] See Bischoff [1969] and Ando, Modigliani, Rasche, and Turnovsky [1974].

[2] The figures in Table 7 reflect the annual number of firms in the investor-owned electric utility industry filing rate-of-return reviews from 1954 to 1977. It should be noted that one firm may have had several filings in various states in any given year. However, this did not affect the tabulated values since they represent the percent of firms filing rate-of-return reviews and not the aggregate number of filings. A variety of alternative proxies for the intensity of regulatory pressure have been suggested. They include the cost of capital, a weighted percent of firms filing rate-of-return reviews (the weighting factor being revenues, number of customers, or gross utility plant), and the actual number of rate-of-return reviews filed as opposed to the percent of firms filing. The task of examining these alternatives is left to another study.

[3] It should be noted that violating certain key assumptions of the A-J analysis may lead to reversals in the effect. For example, Baumol and Klevorick [1970] have demonstrated that a sales-maximizing firm will have incentive to undercapitalize or substitute in the opposite direction. In terms of Appendix C, this implies that equation (93) would be:

$$\frac{-dF}{dk} > \frac{r}{f}$$

Further, Peles and Stein [1976] have shown that in the presence of certain kinds of uncertainty, it is possible to obtain what they term an "anti-A-J effect." They argue that a regulated firm may find it profitable to decrease its use of capital relative to other inputs if the nature of uncertainty is multiplicative. Although these findings offer interesting possibilities for further research, their consideration is beyond the scope of this study.

[4] Griliches [1967] has noted that an $\omega(L)$ polynomial of higher order than two or three implies the estimation of four or five or more coefficients for as many lagged values of the dependent variables. In such a case, reverting back to the $\mu(L)$ form directly would be preferable as it could be approximated by four or five separate lagged values of the independent variable.

[5] See Cooper [1973].

[6] See Maddala [1977, p. 108].

[7] See Jorgenson and Handel [1971, p. 221].

[8] Estimation of equation (49) assuming sum-of-the-years-digits is the method of accelerated depreciation employed in the industry yields slightly different results. These are presented in Appendix D.

[9] See Durbin and Watson [1950].

[10] This is because the test is derived under the assumption that all regressors are fixed. Professor Maddala has pointed out that a distributed lag model estimated in a form such that no lagged dependent variables appear on the right side of the equation may make use of the Durbin-Watson test statistic to test for serial correlation. In such cases, even ignoring the serial correlation would merely result in inefficient but not inconsistent estimates of the parameters.

[11] Rao and Griliches [1969] discuss the fact that in small samples it is not necessarily true that regression statistics are improved if ρ is estimated. They suggest that for samples with N observations (where $N \leq 20$) use of a procedure to account for autocorrelation is justified if $|\hat{\rho}| \geq .3$.

[12] Studies which examine the Averch-Johnson effect include Moore [1970], Spann [1974], Courville [1974], Peterson [1974], Cowing [1975], Hayashi and Trapani [1976], Boyes [1976], Barron and Taggart [1977], and Smithson [1978].

[13] For an excellent overview of this literature see Zimmer [1978].

CHAPTER VII

ALTERNATIVE MODELS OF INVESTMENT BEHAVIOR

In order to ascertain the true value of the investment model as estimated in this study, a comparison of alternative formulations was conducted. Three of the models discussed in Chapter IV offered relatively good explanatory power and dealt with investment behavior of regulated utilities per se. It seemed likely that they might perform as well as the model proposed in this study. The investment functions specified by Jorgenson and Handel [1971], Sankar [1972] and Rennie [1977] were estimated using data for the years 1954-1977. Their assumptions, methodologies, and calculations have been adhered to as strictly as possible.

Jorgenson and Handel

Jorgenson and Handel [1971] formulated an econometric model of investment behavior for total regulated industries and for subindustries of the regulated sector. Their theory of investment behavior is comparable to the approach taken in Chapter IV of this study. However, they neglected to impose the regulatory constraint in the present value maximization problem. This led to an equation for the user cost of capital, c_t, which corresponds to the definition presented on page 19. They assumed a Cobb-Douglas production function

and specified their investment model as a distributed lag function in net investment and changes in the desired capital stock. Employing a rational generating function similar to that used in Chapter IV, quarterly data from the first quarter of 1946 to the fourth quarter of 1960, and gross business income as a measure of output; their specification of the final investment equation for public utilities was:

$$I_t = \gamma \left\{ \frac{P_{t-7}Q_{t-7}}{c_{t-7}} - \frac{P_{t-8}Q_{t-8}}{c_{t-8}} \right\} + \sum_{j=1}^{2} \omega_j \{I_{t-j} - \delta K_{t-j}\} + \delta K_t + \nu_t, \tag{60}$$

where all variables are as previously defined although methods of measurement do differ.

It should be noted that Jorgenson and Handel estimated investment for public utilities as a whole. They failed to separate electric utilities [Standard Industrial Classification (SIC) Codes 4911 and 4912] from the general SIC code for public utilities, i.e., SIC code 49, which includes electric, gas, and sanitary services. Hence, their specification is not quite appropriate for the case of investor-owned electric utilties.

Using gross investment divided by the construction cost index to measure I_t (see Table 4), the depreciation rates from Table 4, price (P) and output (Q) as presented in Table 5, and Jorgenson and Handel's definitions of net investment and the user cost of capital services, equation (60) was estimated using data for the period 1954-1977. The different lag specification reflects the adjustments necessary in converting from quarterly to annual data. The resulting regression is:

$$(61) \qquad I_t = \underset{(.233)}{-.3750} \, (P_{t-2}Q_{t-2}/c_{t-2} - P_{t-3}Q_{t-3}/c_{t-3})$$

$$+ \underset{(.133)}{.8640} \, (I_{t-1} - \delta K_{t-1}) + \underset{(.007)}{.0338} \, K_t + \nu_t$$

$s = 934.2 \qquad R^2 = .9181 \qquad \bar{R}^2 = .9090 \qquad d = 1.0638$

Standard errors are reported in parentheses.

Since serial correlation seemed inherent in the model, the Cochrane-Orcutt iterative technique was employed. The autocorrelation parameter converged to .5687 after four iterations and the final equation was:

$$(62) \qquad I_t = \underset{(.239)}{-.2154} \left(\frac{P_{t-2}Q_{t-2}}{c_{t-2}} - \frac{P_{t-3}Q_{t-3}}{c_{t-3}}\right) + \underset{(.183)}{.7045} \, (I_{t-1} - \delta K_{t-1})$$

$$+ \underset{(.009)}{.0409} \, K_t + \nu_t$$

$s = 821.5 \qquad R^2 = .9379 \qquad \bar{R}^2 = .9306 \qquad d = 1.5162.$

The standard errors reported in parentheses have not been adjusted to reflect estimation of the parameter ρ.

Although the explanatory power of this specification is slightly better than that of equation (49), it does have some undesirable properties. First, a negative sign on the coefficient of the desired capital stock variable does not make much sense. Such a value predicts that investment, I_t, will vary inversely with changes in desired capital stock. That is, firms will decrease investment expenditures in period t when the desired capital stock increases in period t-2. This hardly seems reasonable. Additionally, it violates the constraint condition requiring that the leading coefficients of the $\gamma(L)$ polynomial be nonnegative [1].

Second, the same coefficient is highly insignificant with a t statistic of -.903. This implies that changes in desired capital stock are

irrelevant. Inclusion of such variables will result in unbiased but inefficient estimates of the other parameters and their variances [2]. Most studies of investment behavior in the electric utility industry have found changes in desired capital stock to be significant in explaining net investment [3]. The results of equation (62) run contrary to these findings and imply that the regression may be misspecified.

Third, the coefficient of K_t should approximate the annual depreciation rate. Examination of Table 4 indicates that the estimated value of $\delta(=.0409)$ is too high. The actual aggregate rate of replacement in 1965 was .0268 and represents the highest rate during the period. A comparison of this rate with the coefficient for K_t in equation (62) shows the estimated value of δ to be 52.6 percent above the actual rate.

Given these problems, even the slightly better coefficient of determination cannot justify using the specification offered by Jorgenson and Handel to explain the investment behavior of regulated electric utilities from 1964 to 1977. The investment model derived in this study offers a theoretical and empirical improvement.

Sankar

Sankar [1972] attempted to revise the model offered by Jorgenson and Handel such that it more closely reflected conditions in the regulated electric utility industry. He employed a CES production function in logarithmic form, annual data for the years 1946-1968, a rational distributed lag specification, and a revised formula for the user cost of capital. Arguing that normalization policy [4] "is equivalent to granting an interest-free loan to the utility, while the

flow-through procedure is equivalent to reducing the price of output" [Sankar 1972, p. 65], he assumed that tax policies would influence the price of output and not the user cost of capital. The validity of his assumption hinges on the extent to which regulating authorities aim at keeping the after-tax rate of return constant. If this means nominal, as opposed to real after-tax rates of return, the assumption lacks validity. Since permitted rates of return have risen noticeably over the past few years [5], it is not clear that his assumption is correct [6]. His formula for the user cost of capital reflects his contention and may be written:

(63) $$c_t = (r_t + \delta_t)q_t,$$

where r_t = the cost of capital as measured by Moody's average yield on AAA bonds,

δ_t = the rate of replacement as estimated from his capital stock series (= .04843), and

q_t = the Handy-Whitman index, adjusted such that 1954 = 1.0.

The specification of his final investment function involves relative price lagged two periods, output lagged two periods, and two lagged changes in the capital stock. Using his lag specification, Sankar's assumptions about the user cost of capital, and his methodology for estimating the replacement rate [7], an investment function was estimated with data for the period 1954-1977. The result was:

(64) $$\Delta \ln K_t = \underset{(.037)}{-.0343}\ \Delta \ln\left(\frac{p}{c}\right)_{t-2} + \underset{(.052)}{.0359}\ \Delta \ln O_{t-2} + \underset{(.250)}{1.2301}\ \Delta \ln K_{t-1} - \underset{(.218)}{.3540}\ \Delta \ln K_{t-2} + \nu_t$$

$$s = .0079 \qquad R^2 = .8378 \qquad \bar{R}^2 = .8092 \qquad d = 1.8129.$$

Standard errors are reported in parentheses.

A cursory inspection of equation (64) reveals that the coefficient of the relative price variable has a negative sign. This implies that a negative change in the capital stock should be expected in period t if there is a positive change in relative price in period t-2. Not only does this seem unreasonable, but it also violates the constraint which requires that the leading coefficients of the $\gamma(L)$ polynomial be non-negative [8]. Since the t ratios indicate that neither the relative price nor the output variables are significant, the implications of the constraint violation are not quite clear.

Closer examination shows that the constraint on the coefficients of the lagged dependent variables, ω_1 and ω_2, is satisfied; i.e., $-\omega_2 \geq -\omega_1^2/4$ [9]. The coefficients imply a first-order difference equation which is not explosive, indicating that the lag structure is suitable. However, the explanatory power of (64) is considerably lower than that of (49). This is due partly to the omission of tax effects from the user cost of capital, employment of a depreciation rate that appears to be excessive [10], relatively short lags on the desired capital stock variables, and neglect of the effects implied by rate-of-return regulation. Overall, the investment function specified in equation (49) offers a better model than equation (64) for explaining electric utility investment from 1964 to 1977.

Rennie

Rennie [1977] analyzed the effects of Federal tax policy changes on investment behavior in the power and light industry for the period 1951-1969. He contended that rate-of-return regulation did not insulate

electric utilities from general economic forces and demonstrated that tax policy does affect fixed capital investment in the industry [11].

His theory of investment behavior is one of optimal capital accumulation and is comparable to the theory developed in Chapter IV. He employed a Cobb-Douglas production function, a rational distributed lag specification, and formulae for the user cost of capital equivalent to those used in this study [equations (37) and (38)]. He assumed that sum-of-the-years-digits would be the chosen method for calculating depreciation deductions.

Since he measured variables in much the same manner as they are measured in this study, relatively few adjustments in the data were necessary. However, the estimating program had to be revised to reflect Rennie's final specification which was not in logarithmic form.

The sum-of-the-years-digits formula for depreciation was substituted for the double-declining-balance formulae used in estimating equation (49). Actual depreciation rates for the 1954-1977 period were used as they approximated his estimate of $\delta(=.02587)$. Since Rennie used end-of-the-year capital stock values in his regression, the capital stock values in Table 4 were shifted forward one year to reflect this difference. As in Rennie's study, the Cochrane-Orcutt iterative technique was used. The value of the autocorrelation parameter converged to -.3427 after four iterations, and the final regression was:

$$(65) \quad I_t = \underset{(1866.650)}{2490.33} - \underset{(.247)}{.4719}\Delta K^*_{t-3} + \underset{(.402)}{.1834}\Delta K^*_{t-5} + \underset{(.486)}{.0038}\Delta K^*_{t-8} + \underset{(.398)}{1.0256}\, I^{\varepsilon}_{t-1} + \underset{(.033)}{.0002}\, K_{t-1} + \nu_t$$

$$s = 775.9 \qquad R^2 = .9459 \qquad \bar{R}^2 = .9121 \qquad d = 2.3011 \ ,$$

where I_t^{ε} = investment for expansion (as opposed to that for replacement) in period t,

K_t^* = the desired capital stock in period t as derived from a Cobb-Douglas production function,

and all other variables are as previously defined. The standard errors reported in parentheses have not been adjusted to reflect the fact that ρ has been estimated. However, the constant term as estimated by the statistical package (=3343.77) has been divided by $(1-\hat{\rho})$ to adjust for the Cochrane-Orcutt transformation. In Rennie's work, he makes no mention of either of these problems, so it is assumed he did not account for them.

Equation (65) has slightly more explanatory power than equation (49), but ΔK^*_{t-5}, ΔK^*_{t-8} and K_{t-1} are all highly insignificant with t ratios of .457, .078, and .071, respectively. The inclusion of these irrelevant variables makes the estimates of the other coefficients and their variances unbiased but not efficient [12].

The regression based on Rennie's specification has a rather large constant term. It is interesting to note that his estimate of the constant term was -2499.47. The implications of such an estimate are not quite clear. It might be inferred that if the lagged changes in desired capital stock are zero, then firms would choose to disinvest. This inference is predicated on the assumption that the values of I_{t-1}^{ε} and K_{t-1} are not sufficient to offset the negative constant term. Conversely, the value of the constant term in equation (65) implies that the absence of lagged changes in desired capital stock would still lead to substantial investment. Neither inference is terribly appealing.

The estimated coefficient of the lagged dependent variable should approximate the rate of replacement. Such is clearly not the case in

equation (65). Neither was it the case in Rennie's regression where the estimated value of δ was .2654. Both estimates are unrealistic when compared with the actual and estimated rates discussed earlier.

Finally, the negative coefficient for ΔK^*_{t-3} violates the previously cited constraint requiring that the leading coefficients of the $\gamma(L)$ polynomial be nonnegative. This, coupled with the aforementioned problems in the regression, makes Rennie's specification of the investment function unacceptable for the years 1964-1977.

Of the alternative models investigated, Rennie's seems the most appropriate. The inclusion of Federal tax effects, relatively long lags in investment response and an accelerated depreciaton method serve to boost the explanatory power of his regression. However, none of the alternative specifications produce overall results superior to those of equation (49) for the period with which this study is concerned.

Notes

[1] See Jorgenson and Stephenson [1967, pp. 182-83].

[2] See Kmenta [1971, pp. 396-99].

[3] See Sankar [1972], Rennie [1977], and Figure 4 of this study.

[4] Normalization policy refers to a procedure used by firms who choose an accelerated depreciation method for tax purposes. Since electric utilities must employ the straight-line method for book and rate-making purposes, a difference between taxes paid and taxes incurred will result. This difference is handled in one of two ways. It is either placed in an account known as "Accumulated Deferred Income Taxes" (normalization policy), or passed on to consumers via price reductions (flow-through policy).

[5] This can be seen in Appendix E where the average aggregate earned rates of return have been tabulated. It is recognized that this implicitly assumes that the trend of earned rates reflects the general trend in permitted rates. However, this is probably a valid assumption given the extent of regulatory activity since 1970 (see Table 7).

[6] Rennie [1977] convincingly demonstrates that tax policies do have an effect on investment decisions in the power and light industry when incorporated in the user cost of capital.

[7] This procedure involved generating a new capital stock series and estimating the depreciation rate using Sankar's methodology. The resulting estimate of the rate of replacement for the years 1954-1977 is .04713 which is comparable to Sankar's estimate of .04843. See Sankar [1972, p. 652].

[8] See Jorgenson [1965] and Jorgenson and Stephenson [1967].

[9] See Griliches [1967].

[10] Rennie [1977] derived an estimate of the rate of replacement in the electric utility industry for the years 1951-1969. His estimate was .02587 which bears a close resemblance to the actual rates (see Table 4). Peck [1973] estimated the depreciation rate in two different subsamples of the power and light industry. His figures were .0217 and .0340 which also compare favorably with the rates in Table 4.

[11] It should be noted that all the tax changes considered by Rennie [1977] are accounted for in this study. See Chapter V.

[12] See Maddala [1977, pp. 155-57].

CHAPTER VIII

SUMMARY AND CONCLUSIONS

This study has modified the econometric model of investment behavior in U.S. regulated industries developed by Jorgenson and Handel [1971] such that it more closely reflects conditions in the regulated electric utility industry. Introduction of the regulatory constraint to the profit maximization problem demonstrated that rate-of-return regulation could alter the user cost of capital for privately owned electric utilities. This finding is consistent with the hypothesis advanced by Averch and Johnson [1962].

All previous studies of investment behavior in this industry have failed to impose this constraint and, consequently, ignored its possible effects. The modified model allows for relatively long lags in investment response reflecting the fact that firms in this industry experience such lags between the planning and completion stages of new generating units. It also allows for increasing returns to scale and permits the elasticity of substitution between factor inputs to take on any non-negative value.

Federal tax policy changes influence the cost of fixed capital which, in turn, affects the amount and timing of fixed capital expenditures by utilities [1]. All tax adjustments during the study period have been accounted for in the formulae for the user cost of capital.

The effects of accelerated depreciation methods are incorporated in the calculation of the user cost of capital. Rennie [1977] employed the same approach but assumed sum-of-the-years-digits would be the method chosen by utilities since the present value of the depreciation deduction is higher than that produced when the double-declining-balance method is employed. This holds true for the asset lifetimes and weighted costs of capital used in this study. However, an examination of the results under both methodologies found them to be nearly identical. Since double-declining-balance is the method adopted by the majority of U.S. electric companies, its use seemed more appropriate.

The methodology employed in estimating the effect of rate-of-return regulation on the user cost of capital followed that of Bischoff [1969] and Ando, Modigliani, Rasche, and Turnovsky [1974] who estimated the user cost of capital simultaneously with the coefficients of their investment functions. Joskow [1974] demonstrated that the number of firms filing for rate increases rose whenever the aggregate rate of return in the industry fell. Hence, the percent of firms filing rate-of-return reviews offered a suitable proxy for measuring the intensity of regulatory pressure in any particular year. Altering the user cost of capital by $\alpha\pi_t$ produced estimates of the user cost of capital adjusted for the effects of regulation. The values so obtained were then used in estimating the investment function, equation (35).

The user cost of capital in the absence of regulation, RA_t, is formulated such that all pertinent financial variables are taken into account. Thus, one may infer that the effects of regulation on the user

cost of capital will be reflected in the difference between RA_t and $\hat{R}_t$, the proxy for the user cost of capital adjusted for the effects of regulation. It is the latter which is relevant in determining the coefficients of the investment function for regulated electric utilities. Since α is an unknown parameter, the investment function and the proxy for the user cost of capital adjusted for the effects of regulation must be estimated simultaneously.

The value of α was varied at intervals of 0.001 from -.194 to 1.0. All possible formulations of the investment function were estimated for each value of α, RA_t, and resulting $\hat{R}_t$. The investment function chosen minimized the standard error of the regression subject to the condition that the leading coefficients of the $\gamma(L)$ polynomial be nonnegative.

The value of α consistently yielding the best explanatory power for the investment function is -.015. Thus, RA_t, the user cost of capital in the absence of regulation falls somewhat when rate-of-return regulation is imposed. This result lends support to the Averch-Johnson hypothesis in that a decrease in the cost of capital relative to that of other inputs suggests there may be over capitalization in the industry. Firms may find it advantageous to substitute capital for other factor inputs in the presence of rate-of-return regulation.

In attempting to account for the effects of rate-of-return regulation on the investment behavior of regulated electric utilities, an untried approach to testing the Averch-Johnson effect evolved. Estimation of the investment function simultaneously with the effective user

cost of capital, $\hat{R}_t$, reveals that investment behavior of privately owned electric utilities is best explained when the user cost of capital is reduced slightly.

Several modifications of the final investment equation were considered. None rendered an improvement in the explanatory power of equation (49). However, the possibility exists that the modifications are improperly introduced into the model. Since they do offer intuitive appeal, further investigation seems warranted. It is beyond the scope of this paper to undertake such investigation. It does seem reasonable, however, that the model of investment behavior developed in this study could be extended to correctly reflect the effects of changing scale economies on industry investment decisions. Additionally, future studies might examine sales-maximization as proposed by Baumol and Klevorick [1970] or introduce different types of uncertainty as suggested by Peles and Stein [1976].

When compared with alternative models of investment behavior in regulated industries, the model developed in this study offers both a theoretical and empirical improvement. Its overall performance for the period 1964-1977 is better than the specifications offered by Jorgenson and Handel [1971], Sankar [1972], and Rennie [1977].

It is the first model of investment behavior for this sector of the economy which incorporates the effects of rate-of-return regulation. The method of constructing the capital stock series is consistent with the assumption that replacement investment is proportional to net capital stock. The model accounts for depreciation on new plant and equipment

and utilizes actual depreciation rates in the industry, neither of which has been incorporated in previous studies. Examination of Figure 5 reveals that the model has relatively good explanatory power and is capable of predicting turning points well.

Using data from 1954-1977, coefficients were estimated relating net investment to changes in desired captial stock and lagged net investment. The effects of relative price and output were estimated separately. Long-run elasticities of capital stock with respect to both variables were calculated and seemed to be of reasonable magnitude. The equation explained 91.8 percent of the variation in net investment and implied an average lag of about 8.96 between changes in output and changes in net investment. This is slightly higher than Rennie's estimate of 8.30 but consistent in light of the fact that lead times have been increasing since 1969.

The coefficients for lagged changes in output were significantly higher than those for the corresponding changes in relative price. This result is not surprising. The long-term planning considerations and large capital outlays involved with construction of new generating facilities make electric utility investment decisions heavily dependent on demand considerations. Thus, the divergence seems plausible.

This study of the investment behavior of regulated electric uitlities is the first to consider the effects of rate-of-return regulation on the user cost of capital. In so doing, it offers a fresh approach for testing the validity of the A-J hypothesis. It incorporates the investment behavior of electric utilities which is central to the entire A-J

analysis. Since the explanatory power of the investment function is increased when the user cost of capital is reduced slightly, this study offers some evidence that the A-J effect may, in fact, occur.

It should be noted, however, that other forces at work here may make this test inconclusive. First, the rapid and significant escalation of fuel prices may have caused utilities to substitute capital for fuel, resulting in overcapitalization. Second, investment in pollution control facilities in accordance with environmental legislation may have contributed to a greater capital stock than that dictated by profit-maximization principles. However, the increased trend toward power pooling may serve to mitigate these effects somewhat in that capital requirements are reduced when power pooling is employed. The overall effect is not clear at present, but certainly deserves further investigation such that the true value of the findings of this study may be ascertained.

Notes

[1] This has been shown convincingly by Rennie [1977].

APPENDIX A

PROPERTIES OF A CONSTANT ELASTICITY OF SUBSTITUTION (CES) PRODUCTION FUNCTION

Arrow, Chenery, Minhas and Solow [1961] have shown that the class of CES production functions may be expressed in the form:

$$(66) \qquad Q = A[\alpha K^{-\rho} + (1 - \alpha)F^{-\rho}]^{-k/\rho} ,$$

where all variables are as defined in Chapter IV and the parameters A 0 and $0 < \alpha < 1$. Since $A[\alpha bK^{-\rho} + (1-\alpha)bF^{-\rho}]^{-k/\rho} = bA[\alpha K^{-\rho} + (1-\alpha)F^{-\rho}]^{-k/\rho}$, equation (66) is homogeneous of degree one.

The marginal productivities of the inputs are:

$$(67) \qquad \frac{\partial Q}{\partial K} = Q_K = \alpha kA[\alpha K^{-\rho} + (1-\alpha)F^{-\rho}]^{-k/\rho-1}[K^{-\rho-1}]$$

and

$$(68) \qquad \frac{\partial Q}{\partial F} = Q_F = (1-\alpha)kA[\alpha K^{-\rho} + (1-\alpha)F^{-\rho}]^{-k/\rho-1}[K^{-\rho-1}].$$

Thus, the rate of technical substitution (RTS) is given by:

$$(69) \qquad \frac{\frac{\partial Q}{\partial K}}{\frac{\partial Q}{\partial F}} = \frac{\alpha}{1-\alpha}\left[\frac{F}{K}\right]^{\rho+1}.$$

The expression for the elasticity of substitution (σ), equation (26), is derived as follows. If σ represents a pure number which measures the rate at which substitution takes place between K and L, it is defined as the proportionate rate of change in the input ratio divided by the proportionate rate of change in the RTS, or:

$$(70) \quad \sigma = \frac{\partial \ell n(F/K)}{\partial \ell n(Q_K/Q_F)} = \frac{d(F/K)/(F/K)}{d(Q_K/Q_F)/(Q_K/Q_F)}$$

Substituting equations (67) and (68) into (70) yields:

$$(71) \quad \sigma = [\alpha(1-\alpha)(F/K)/(F/K)][1/[(\rho+1)\alpha/(1-\alpha)(F/K)^{\rho}]],$$

which simplifies to:

$$(72) \quad \sigma = \frac{1}{1+\rho},$$

or equation (26). Similarly, it may be shown that:

$$(73) \quad \sigma = \frac{\partial \ell n(K/F)}{\partial \ell n(Q_F/Q_K)} = \frac{1}{1+\rho},$$

and all partial elasticities of substitution will be equal. From (72), it can be seen that:

$$(74) \quad \rho = \frac{1-\sigma}{\sigma} .$$

Thus, the parameter ρ is closely related to the constant elasticity of substitution.

Differentiating (69) gives:

$$(75) \quad \frac{\partial^2 F}{\partial K^2} = -(\rho+1)\frac{\alpha}{(1-\alpha)^2}\frac{F^{(\alpha+1)}}{K^{2(\alpha+1)}}[(1-\alpha)K^{\rho} + \alpha F^{\rho}].$$

The RTS is decreasing and isoquants are convex if $\rho > -1$. The particular shape of the convex isoquants generated by a CES function depends on the value of σ. In this study, the following case describes the isoquant configurations.

Since $0<\hat{\sigma}<1$ (see Chapter VI) and $\rho>0$, the isoquants for equation (27) may be written as:

(76) $\alpha K^{-\rho} + (1-\alpha)F^{-\rho} = (Q/A)^{-\rho} = T,$

where T is a positive constant for any given value of Q. Both terms on the left-hand side of (76) must be greater than or equal to zero. Thus, neither term can exceed T in value. As $K \to 0$, $\alpha K^{-\rho} \to +\infty$. Since there is an upper limit, T, on the value of $\alpha K^{-\rho}$, K cannot equal zero. By similar reasoning, F cannot equal zero. Thus, the isoquants are asymptotic to $K = (T/\alpha)^{-(1/\rho)}$ and $F = \{T/(1-\alpha)\}^{-(1/\rho)}$.

APPENDIX B

CONVERSION OF A CES FUNCTION TO A COBB-DOUGLAS FORMULATION

It has been observed that a CES production function becomes a Cobb-Doublas function when $\sigma=1$. The interpretation of this case is not clear from equation (26). By equation (26), $\sigma=1$ implies $\rho=0$. When the parameter $\rho = 0$, equation (76) in Appendix A becomes an identity. Thus, it is of no assistance in establishing the properties of this case.

However, L'Hôpital's rule states that if:

$$(77) \qquad \lim_{x \to z} f(x) = 0 \text{ and } \lim_{x \to z} g(x) = 0,$$

and if:

$$(78) \qquad \lim_{x \to z} \frac{f'(x)}{g'(x)} = \theta,$$

then:

$$(79) \qquad \lim_{x \to z} \frac{f(x)}{g(x)} = \theta.$$

And equation (26) may be written in logarithmic form as :

$$(80) \qquad \ln Q - \ln A = \frac{-\ln[\alpha k^{-\rho} + (1-\alpha)F^{-\rho}]}{\rho},$$

which is a quotient of two functions of ρ. That is:

$$(81) \qquad \ln Q - \ln A = \frac{f(\rho)}{g(\rho)}$$

where $f(\rho) \to 0$ and $g(\rho) \to 0$ as $\rho \to 0$. Finally, $g'(\rho) = 1$. By L'Hôpital's rule, the limiting case is:

(82) $$\ell n\, Q - \ell n A = \alpha\, \ell n\, K + (1-\alpha)\, \ell n F,$$

and:

(83) $$Q = AK^{\alpha}F^{(1-\alpha)},$$

which is a function of the Cobb-Douglas form. Q.E.D.

APPENDIX C

MATHEMATICAL DERIVATION OF THE AVERCH-JOHNSON EFFECT

Since electric utilities are granted a monopoly status in their service area, this analysis will deal with a monopoly market structure and will follow the proof offered by Averch and Johnson [1962] as closely as possible. Assuming the firm produces a single homogeneous product, such as electricty (Q), using two factor inputs, say capital (K) and fuel (F), then:

$$Q = Q(K,F),$$

$$K \geq 0, \; F \geq 0,$$

$$\partial Q/\partial K > 0, \; \partial Q/\partial F > 0,$$

$$Q(0,F) = Q(K,0) = 0,$$

defines the firm's production function. The marginal products are positive and the absence of either input results in zero production.

The inverse demand function may be written as:

$$P = P(Q)$$

and profit as:

$$\pi = PQ(K,F) - rK - fF, \tag{84}$$

where r is the cost of capital and f the cost of fuel. It is assumed

that these costs will not be affected by the amounts used in this sector of the economy, but will remain constant across all levels of output.

If K denotes the utility plant and equipment that comprise the rate base, q the acquisition cost per unit of K in the rate base, z the value of depreciation of K during any time period, and Z the accumulated depreciation value, then the regulatory constraint is:

$$\frac{PQ(K,F)-fF-z}{qK-Z} \leq s, \tag{85}$$

where the profit less fuel cost and capital depreciation represents a proportion of the rate base less than or equal to s, the allowed rate of return.

Normalizing the acquisition cost or value of capital, q, such that q = 1, and assuming depreciation (z and Z) is zero simplifies the analysis but does not affect the results. The cost of capital, r (as distinguished from the cost of plant and equipment measured by q) is the cost incurred by holding plant and equipment. The allowable rate of return, s, is the rate of return permitted on the rate base by the regulating authority. It presumably compensates the firm for the cost of capital---interest cost---involved in holding plant and equipment. Thus, equation (85) may alternatively be written as:

$$\frac{PQ(K,F)-fF}{K} \leq s, \tag{86}$$

or

$$PQ(K,F)-sK-fF \leq 0. \tag{87}$$

When $s<r$, the permitted rate of return is less than the actual cost of capital, and the firm would be expected to cease production. For, from equation (87), if $K>0$,

(88) $$PQ(K,F)-rK-fF = PQ(K,F)-sK+(s-r)K-fF \leq (s-r)K < 0.$$

If $K = 0$, $\pi = -fF$ from equation (84), and the firm can reduce its loss by setting $F = 0$. Then $\pi = 0$. Therefore, $s \geq r$; and the permitted rate of return must at least cover the cost of capital in order for production to be profitable.

Thus, the firm's problem is one of maximizing (84) subject to (87). Although the formulation of (87) presents a nonlinear programming problem, the results are similar to those of ordinary marginal conditions.

The appropriate Lagrangian expression is:

(89) $$\mathcal{L}(K,F,\lambda) = PQ(K,F)-rK-fF-\lambda[PQ(K,F)-sK-fF].$$

The necessary Kuhn-Tucker conditions for a maximum are:

(90a) $$r \geq (1-\lambda)[P+Q\frac{\partial P}{\partial Q}]\frac{\partial Q}{\partial K}+\lambda s, \quad K \geq 0,$$

(90b) $$r > (1-\lambda)[P+Q\frac{\partial P}{\partial Q}]\frac{\partial P}{\partial Q}+\lambda s,$$

(90c) $$(1-\lambda)f \geq (1-\lambda)[P+Q\frac{\partial P}{\partial Q}]\frac{\partial Q}{\partial F}, \quad F \geq 0,$$

(90d) $$(1-\lambda)f > (1-\lambda)[P+Q\frac{\partial P}{\partial Q}]\frac{\partial Q}{\partial F},$$

(90e) $$PQ(K,F)-sK-fF \leq 0, \qquad \lambda \geq 0, \text{ and}$$

(90f) $$PQ(K,F)-fF < sK.$$

Equations (90b), (90d), and (90e) imply that $K = 0$, $F = 0$, and $\lambda = 0$ respectively at the maximum.

If λ_o represents λ at the maximum and if $\lambda_o > 0$, (90a) implies that $\lambda = 1$ if and only if $r = s$. Since this involves no variables, any K or F which satisfies (90e) becomes a solution.

If $s > r$, it follows that $0 \leq \alpha < 1$. In (90f), if s is large enough, $\lambda = 0$. That is, if the level of permitted rate of return is $s = s^*$, the value of $K(s^* - r)$ will exceed the level of unconditionally maximized profit, and the constraint (87) will be ineffective.

As the value of s approaches that of r, λ varies continuously, and since $\lambda \neq 1$, $0 < \lambda < 1$. For an unregulated firm, the marginal conditions are:

(91) $$r/f = (\partial Q/\partial K)/(\partial Q/\partial F).$$

When regulation is effective, equations (90c) and (90d) show that input F is employed in the production process such that its marginal cost, f, equals its marginal value product (MVP). This is the same result as is the case of an unregulated firm. In contrast, (90a) and (91) show that the input of K is such that its marginal cost, r, exceeds its MVP. That is, the regulated firm expands its use of K beyond the point where its marginal cost equals its MVP.

From equations (90a) and (90c) when the equalities hold, the marginal rate of substitution (MRS) of K for F is:

(92) $$\frac{-dF}{dK} = \frac{r}{f} - \frac{\lambda}{1-\lambda}\frac{(s-r)}{f} .$$

Since

$$\frac{\lambda}{(1-\lambda)} \; \frac{(s-r)}{f} > 0, \; \lambda>0, \text{ and } s>r,$$

equation (92) implies:

(93) $$- \frac{dF}{dK} < \frac{r}{f} ,$$

and the firm adjusts to the regulatory constraint by substituting K for F and expanding total output.

APPENDIX D

INVESTMENT FUNCTION ESTIMATES ASSUMING SUM-OF-THE-YEARS-DIGITS DEPRECIATION PRACTICES

One purpose of this study is to improve upon previous studies of investment behavior in the electrtic utility industry. Existing models have consistently assumed that companies would choose the method of accelerated depreciation which had the largest present value. As Tables 2 and 3 demonstrate, such an assumption dictates that sum-of-the-years-digits be employed. However, Brigham [1966] presents evidence that most utilities employ the double-declining-balance method. Since it is more representative of industry practice, the double-declining-balance technique is the method used in estimating equation (49).

Using the sum-of-the-years-digits formula in estimating equation (49) results in the following investment function parameters:

$$\begin{aligned}(94)\quad \Delta\ell n\ K_t = &\underset{(.016)}{.0340}\,\Delta\ell n\ \left(\frac{P}{c}\right)_{t-6} + \underset{(.060)}{.0812}\,\Delta\ell n\ Q_{t-6} \\ &+ \underset{(.021)}{.0769}\,\Delta\ell n\ \left(\frac{P}{c}\right)_{t-8} + \underset{(.054)}{.1345}\,\Delta\ell n\ Q_{t-8} \\ &+ \underset{(.094)}{.8243}\,\Delta\ell n\ K_{t-1} + \nu_t\end{aligned}$$

$$s = .0051 \qquad R^2 = .9178 \qquad \bar{R}^2 = .8849 \qquad d = 2.0973.$$

Standard errors are reported in parentheses. Detailed statistics are presented in Figure 11. The actual and fitted values and residuals are plotted in Figure 12.

A comparison of equations (49) and (94) shows them to be strikingly similar. However, use of the double-declining-balance method does lead

ORDINARY LEAST SQUARES

VARIABLES...

CLDK8
CLP6
CLQ6
CLP8
CLQ8
CLDK81

INDEPENDENT VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
CLP6	0.339517E-01	0.158161E-01	2.14666
CLQ6	0.812304E-01	0.602442E-01	1.34835
CLP8	0.766611E-01	0.205605E-01	3.73324
CLQ8	0.134523	0.513729E-01	2.61855
CLDK81	0.824348	0.941617E-01	8.75460

R-SQUARED = 0.9173

F-STATISTIC(4, 10) = 27.9010

DURBIN-WATSON STATISTIC (ADJ. FOR 0 GAPS) = 2.0973

NUMBER OF OBSERVATIONS = 15

SUM OF SQUARED RESIDUALS = 0.257917E-03

STANDARD ERROR OF THE REGRESSION = 0.507856E-02

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

0.250E-03	0.249E-03	-0.414E-04	-0.226E-03	0.201E-03
0.249E-03	0.363E-02	0.145E-03	-0.306E-03	-0.391E-02
-0.414E-04	0.145E-03	0.423E-03	0.691E-03	-0.729E-03
-0.226E-03	-0.306E-03	0.691E-03	0.264E-02	-0.269E-02
0.201E-03	-0.391E-02	-0.729E-03	-0.269E-02	0.887E-02

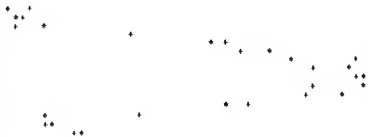
FIGURE 11

DETAILED REGRESSION RESULTS FOR THE INVESTMENT FUNCTION
ASSUMING SUM-OF-THE-YEARS-DIGITS DEPRECIATION PRACTICES

PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(*)

ID	ACTUAL	FITTED	RESIDUAL
1963	0.2949E-01	0.3216E-01	-0.267E-02
1964	0.2992E-01	0.3071E-01	-0.789E-03
1965	0.3346E-01	0.3027E-01	0.320E-02
1966	0.4299E-01	0.4291E-01	0.720E-04
1967	0.5173E-01	0.5273E-01	-0.100E-02
1968	0.5806E-01	0.5502E-01	0.305E-02
1969	0.6040E-01	0.6756E-01	-0.716E-02
1970	0.6607E-01	0.6244E-01	0.362E-02
1971	0.6802E-01	0.6703E-01	0.992E-03
1972	0.6783E-01	0.6233E-01	0.550E-02
1973	0.6569E-01	0.6159E-01	0.410E-02
1974	0.5290E-01	0.5553E-01	-0.264E-02
1975	0.3326E-01	0.4360E-01	-0.103E-01
1976	0.3452E-01	0.3304E-01	0.149E-02
1977	0.3732E-01	0.3622E-01	0.109E-02



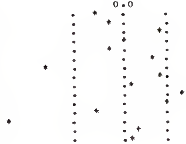


FIGURE 12

ACTUAL AND FITTED VALUES OF $\Delta \ell n K_t$ AND RESULTING RESIDUALS FROM EQUATION (94)

to slightly better results. In view of this, and the fact that it is more widely employed in the industry justifies the use of the double-declining-balance formula in this analysis.

APPENDIX E

AGGREGATE AVERAGE RATES OF RETURN ON ORIGINAL COST RATE BASE

Year	Rate Of Return
1970	.073
1971	.074
1972	.076
1973	.076
1974	.076
1975	.082
1976	.086

Source: U.S. Federal Energy Regulatory Commission [1978] and U. S. Federal Power Commission [1972-1977].

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Gael P. Penland was born March 15, 1949, in New York City, New York. She attended Suitland High School in Suitland, Maryland. Her undergraduate education was received at the University of Florida in Gainesville, Florida. In 1971, she was awarded a B. A. in economics with honors and was admitted to membership in Phi Beta Kappa. Since then she has attended graduate school at Rollins College in Winter Park, Florida, where she received an M. S. in Management in 1975. In 1976, she returned to the University of Florida to continue her graduate work and subsequently was granted an M. A. in economics in 1977.

I certify that I have read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

G. S. Maddala, Chairman
Professor of Economics

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